JOURNAL OF



# Metals

## TECHNOLOGY · PRACTICE

JUNE 1949

**U.S. Mineral Policy**

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**pen Hearth Conference**

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**Howe Lecture**

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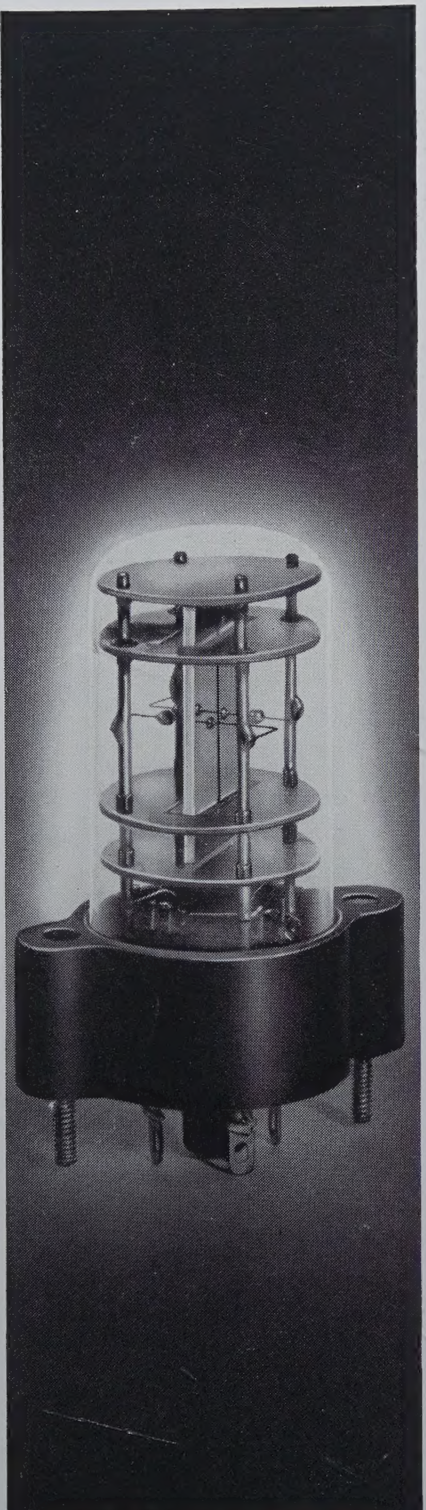
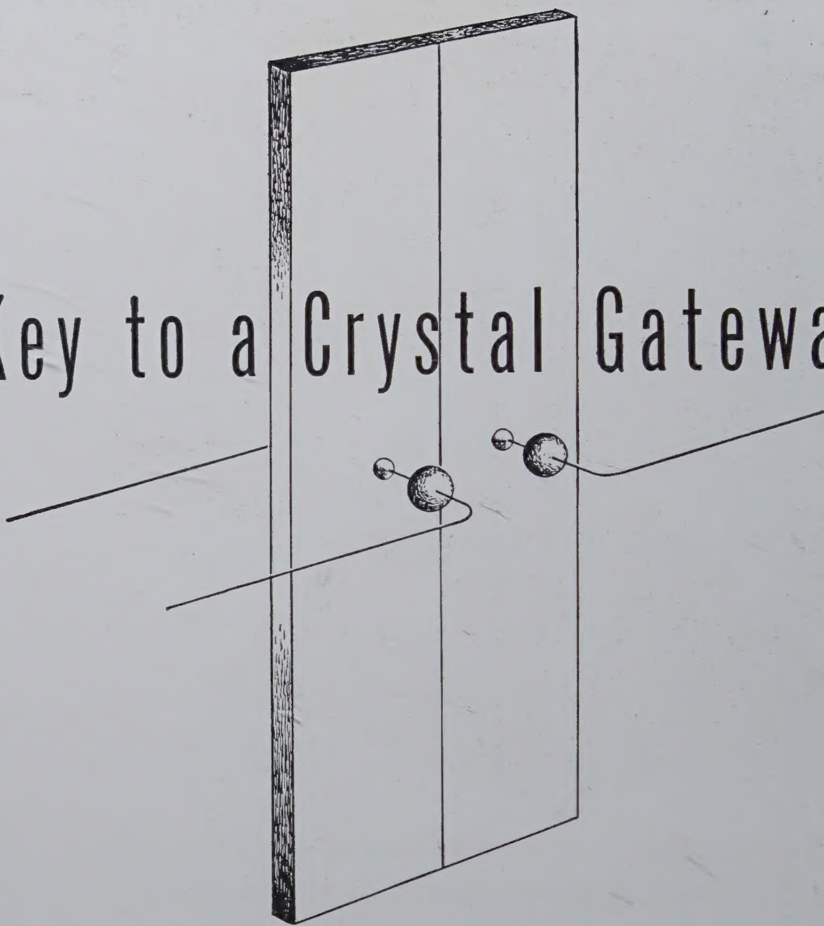
**tals Branch Committees**

A MONTHLY PUBLICATION OF THE
AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS
METALS BRANCH



*Above is a coaxial circuit crystal in its glass enclosure. At right the crystal is shown, 3½ times actual size, with connecting wires soldered in position. Weights on wires reflect energy back into crystal, so cut losses.*

# Key to a Crystal Gateway



How would you solder a wire to a crystal? This must be done for most of those wafer-thin plates of quartz used in electrical circuits. They play a big part in the myriad-channel telephone system that utilizes coaxial cables.

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This spot of paste, this tiny wire, this puff of air are among the tremendous trifles which concern Bell Telephone Laboratories in finding new ways to improve your telephone service.

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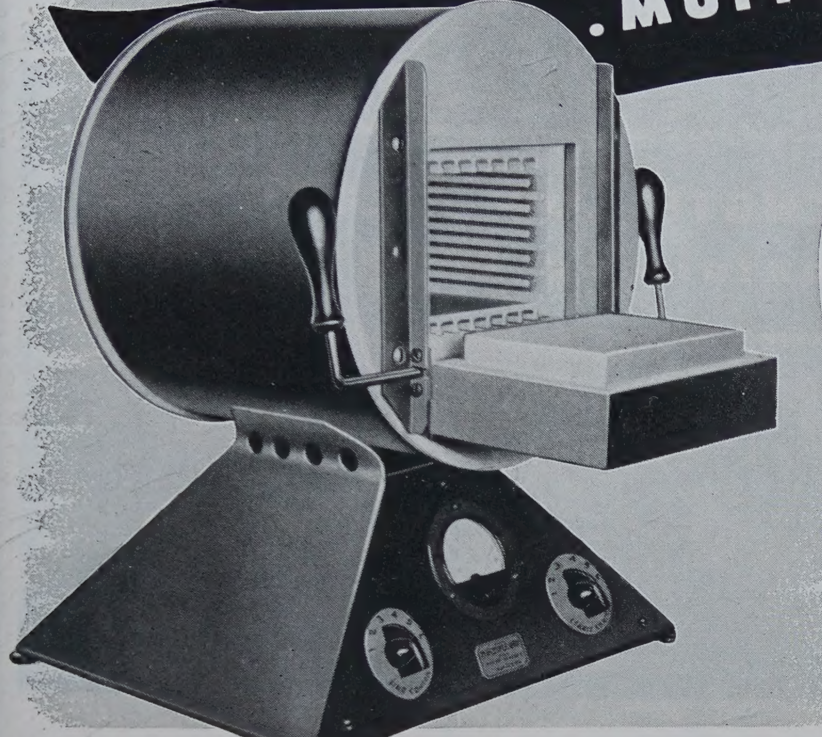
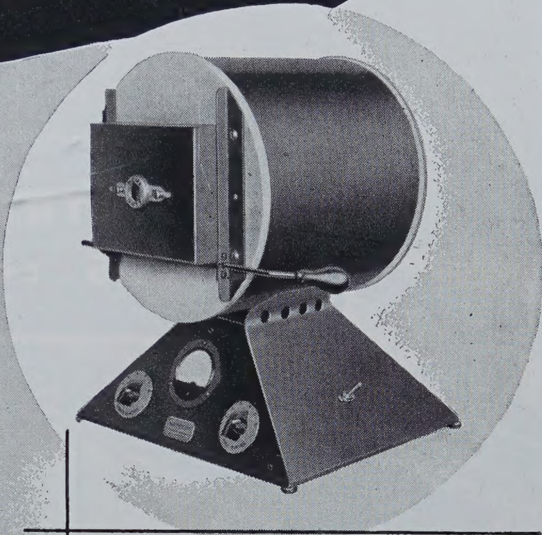
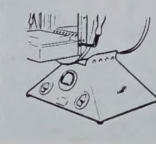
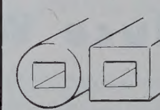


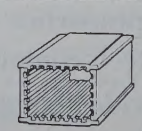




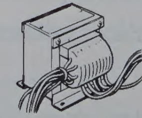
Instruments and Controls operate at approximately room temperature . . . there is no trapped heat.



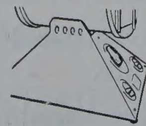

As a result of correct insulation design, you can shift rapidly to desired operating temperatures.



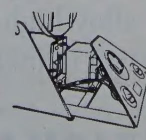
Reversible and easily replaceable Multiple Units, time-tested for 30 years, have been retained.



36 steps of control through a Hevi Duty Tap-Changing Transformer allows maximum flexibility of control.



Controls are mounted in a recessed position for safety and at correct angle for proper vision.



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# JOURNAL OF Metals

TECHNOLOGY · PRACTICE





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June 1949

Vol. I, No. 6


COVER: Tapping an open hearth furnace at the Edgar Thomson Works, Braddock, Pa., Carnegie-Illinois Steel Corp. *(U. S. Steel photo)*

***section one***




Pages 21-24 of Sect. I follow Transactions Section




***section two . . . AIME***



***section three . . . metals transactions***




(TECHNICAL NOTE EXPLANATION ON PAGE 364)



AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS, INC.
Metals Branch
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AIME also publishes *Mining Engineering* and *Journal of Petroleum Technology*.

## PHOTO REMINDER

We told you last month about the cover photo contest of the Journal of Metals—wherein all members and readers are urged to submit good photographs, related to the metals field, that would be suitable for a front cover. This front cover is our store window, so to speak, designed to entice present and potential readers inside. So we naturally want a good display in that window.

Specifications and tolerances for a good photo are: Not too dark overall, some good contrasts between light and dark, not too much detail. Naturally the more striking and unusual photo will elicit more interest than a more prosaic picture, but the latter is not to be ignored.

The winner will receive a year's dues to AIME for free. Any picture used, if not the first prize winner, will entitle the contestant to any copy of the IMD's symposium volumes. The contest closes Sept. 1, 1949. All entries will be acknowledged by postcard. Glossy prints are essential. All entries are the property of JOURNAL OF METALS. None is returnable.

Send 'em in, please!

JOURNAL OF
Metals
TECHNOLOGY · PRACTICE

## GUEST EDITORIAL

**C. DONALD DALLAS** • CHAIRMAN OF THE BOARD, REVERE COPPER AND BRASS, INC.

# *THE LONG VIEW OF MINERAL POLICY*

It is fair to say that short term rather than long term thinking has determined our attitude toward the essential non-ferrous metals. The nearest we have had to a national policy is the theory or belief that domestic supplies of minerals such as copper should be used to the utmost and foreign supplies excluded, except in periods of patent inability of domestic supplies to meet the needs of industry and the armed services.

As a symptom of the nearby view we might consider the tariff on copper, which is currently "suspended," as a temporary measure, to June 30, 1950. Reasoning on behalf of the tariff is that by such means domestic production is encouraged; we are helped to self-sufficiency and therefore to a stronger position in war as well as in peace. The fallacy of such a position has been clearly demonstrated by events—through over-use of domestic reserves we have become not stronger but weaker; more, not less, dependent upon continued foreign production and supplies. In effect, we are well on the way to being a "have-not" nation in copper.

It is possible to believe that domestic copper mining is essential, without holding that "protection" is essential for the industry. Here is where the long-term view is decisive. We can take this look into the future without entering the controversy concerning the adequacy of our underground reserves. Some authorities consider the supply as sufficient for only 20 to 30 years, even with processing of ores that are unprofitably low in copper at current prices. Others say that new ore bodies will be discovered and developed as needed.

The copper mining industry, in the long run, can expect a greater demand for its metal than can be met even by a substantially high level of domestic production. United States consumption of copper has been running well over 1,300,000 tons a year, exclusive of stockpiling. To meet this need there is a theoretical maximum mine production capacity of 875,000 tons, which has not been reached because of interruptions such as strikes. The deficit is made up by use of scrap and by imports which last year amounted to 500,000 tons of copper in various forms.

In the past, copper consumption has been tied closely to the general level of business, as expressed in such figures as those for gross national product. The Twentieth Century Fund, in its thorough study of America's resources, found that it would be reasonable to expect in 1960 a gross national product of about $153,000,000,000 (in 1940 dollars). On the basis of past relationships this would mean copper consumption of 1,600,000 tons in 1960. A rather more optimistic calculation by Dr. Weidenhammer of the Department of Commerce puts the consumption figure for that year at more than 2,000,000 tons.

During the decade ahead we may expect a continuation of the extraordinarily high rate of peacetime expenditure on the armed services. The current budget of $15,000,000,000 for the military means an undisclosed but tremendous addition to the amount of copper required for strictly civilian production, and there are few who dare to hope for any smaller military expenditures in the years immediately ahead.

These are among the reasons why the copper mining industry can feel secure about its future in the American economy and why it need not rely upon a tariff for short term "protection." The only circumstance that can upset these relationships is an artificially high price for copper, which would curtail the normal consumption of the metal due to the encouragement of substitute metals which are in ample domestic supply.

The independent fabricator of copper, not allied with a mining company, must be concerned about control measures which would tend to divert consumption to substitute metals. Such an independent can as logically call for a subsidy to compensate for high prices as a mining company can call for a tariff to guard against low prices.

Both will do well to ask no governmental protection but to be consistent in practice with the principles of free enterprise. There is no protection without control, and no control without regimentation and hence without loss of freedom.

Fellowship Dinner, Thirty-second Annual Conference, Open Hearth and Blast Furnace, Coke Oven and Raw Materials Committees, at the Palmer House, Chicago, April 19, 1949.

# 1949 Open Hearth Conference

## *Sulphur Elimination, Basic Lined Furnaces, Oxygen Discussed*

Reported by **WALTER CARROLL** • GENERAL METALLURGIST, REPUBLIC STEEL CORP.

To those who are interested in applied sciences and who have been surfeited with the wonders of the atom the 1949 session of the Open Hearth Steel Committee was a refreshing interlude in the hurly-burly of the daily chores. This three-day affair, at Chicago April 18-20, was a man to man, frank, and open discussion of the problems of the open hearth operators, without the use of a single integral sign. Nor was there too much indulgence in abstruse theories or mental gymnastics so dear to the heart of the mathematician. In putting down what transpired, the reviewer must limit himself to the space allotted to him. This is in spite of the fact that some of the most important, at least the most interesting, statements were made in the short, more unscientific Anglo Saxon words used during the extra curricular activities. The entire affair was well run and showed the results of carefully thought out plans. The few cases of straying from the scheduled path were natural consequences of vigorous comments during the discussion period.

The plant visit, on the opening day, to the Gary Works, U. S. Steel Corp., was the oustanding event, well carried out. The visitors were politely and diplomatically conducted along the tour with plenty of time for the asking, and, what is more important, the answering of pertinent questions. It was as though the entire plant were open to inspection with nothing held back. This visit was a pleasure to the many men who in their past careers have worked at Gary, as well as those who are not "alumni" of the world's largest steel plant. The family style dinner was in keeping with the scale on which the tour was conducted. It is to be regretted that the weather man did not have better control of his department.

The actual work of the Conference opened on Tuesday, April 19, with the General Session of the Acid and Basic Open Hearth Sections presided over by E. G. Hill, Wheeling Steel Corp., who, as Acting Chairman, welcomed the visitors to Chicago in general and to the Conference in particular. As is customary, the McKune Award paper was read at the session. This award, established in 1940 in memory of Frank B. McKune, a long-time open hearth superintendent of the Steel Co. of Canada, Ltd., as well as a faithful and active pioneer in the work of the Open Hearth Committee, is given annually to the best paper, of not more than 5000 words, on open hearth practice. It involves a Certificate of Award, $200 cash, as well as the recipient's Conference expenses. To stimulate the younger engineers the award is confined to those not more than 35 years of age.

### McKune award paper

The recipient of the 1949 McKune award was Theodore B. Winkler, Research Engineer, Bethlehem Steel Co., Bethlehem, Pa. His paper, on "Liquid Iron and Steel Temperatures in Practice," may be best expressed in the author's own words: "Platinum immersion thermocouples were used experimentally to produce information on liquid iron and steel temperatures at various stages in both the basic-electric and basic open hearth processes."

Dr. Winkler gave an interesting presentation of the relative changes in temperatures at important steps in the refining operations, beginning with the iron as it came from the blast furnace, on through to the final steel ready to be poured from the teeming ladle into the ingot. Dr. Winkler, in describing the details of his apparatus (See Fig. 1), thought that "it may be well to emphasize that this pyrometer is not a fool-proof instrument; however, the care and judgment are not prohibitive."

Included in the paper was the following interesting tabulation:

**Temperature Variation of Hot Metal**

| | |
|---|---|
| Maximum variation from cast to cast.... | 2600 F to 2765 F |
| Maximum variation within a cast........ | 75 F |
| Drop from skimmer to full submarine transfer ladle ........................ | 100 F |
| Drop in submarine ladle during approx. 1½ hr. transfer from blast furnace to open-hearth mixer .................... | 40 F |
| Drop in open-top transfer ladle during approx. 1½ hr. transfer from blast furnace to open hearth mixer............ | 80 F |
| Drop from submarine ladle, through mixer, to open-hearth hot-metal ladle........ | 140 F |
| Maximum variation in open-hearth hot-metal ladles ........................ | 2375 F to 2425 F |

The McKune Award, with its personal honor, backed up by a substantial financial remuneration, is fulfilling the purpose of its establishment, namely to give the younger engineers the opportunity to take an active part in the work and discussions of the Conference. It was justly earned in 1949.

With the completion of this General Session the members reshuffled themselves into the various sectional activities that best suited their individual preferences. "Basic Open Hearth Operating Session I" devoted itself to the "Problems of Sulphur Elimination." At the same time the "Acid Open Hearth Operations" were discussed by those more interested in that particular specialty.

The afternoon sessions were divided among "Basic Open Hearth Operating Session II" and the session on "Cold Metal Operations and Basic Foundry Practice." Both sessions covered a wide range of subjects, each of which plays its important role in the industry.

Wednesday, April 20, also had two morning sessions running concurrently. That on "Refractories and Masonry" included "Progress Reports on Basic Lined Furnaces, Mixer Linings and Roof Life vs. Silica Brick Quality." The other session on "Metallurgy of the Open Hearth Process," "Covered Deoxidation Practices" and the "Mechanism of Foaming (Slags)."

The afternoon was given over to the "Quality Session" in which the discussion covered the various advantages and disadvantages associated with the different treatments of steel ingots and the subsequent products. An important part of this session was a paper on "Safety" by D. A. Farrell, Supervisor of Safety of Carnegie-Illinois Steel Corp., who put his subject across with a novel and effective use of explanatory slides.

## fellowship dinner

The social phase of the Conference was the Annual Fellowship Dinner held Tuesday evening. E. G. Hill tendered the customary presentation of a Certificate of Life Membership to the Past Chairman, W. C. Kitto, after which he conducted the formal presentation of the McKune Award to T. B. Winkler and presented Conference Awards to Russel Fayles and Fred Jaicks. After

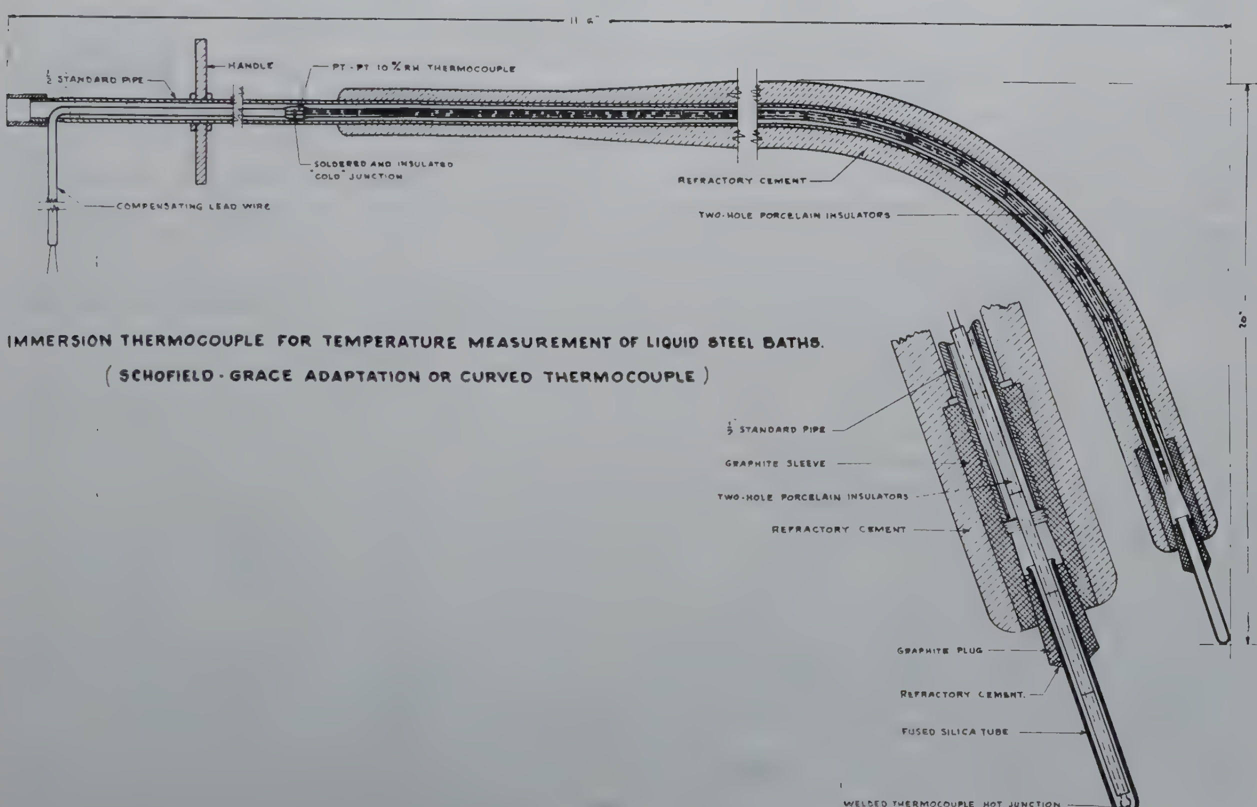



Fig. 1—Immersion Thermocouple for Temperature Measurement of Liquid Steel Baths.

this "warm-up turn" the gavel was turned over to Harry P. Watt, Manager of Sales, Western Area, Carnegie-Illinois Steel Corp. Mr. Watt very graciously presented to the audience Clarence B. Randall, recently named President, Inland Steel Co., who conveyed to his listeners a very provocative message, the residue of which will be left in the individual minds of his listeners long after the rest of his talk has been forgotten.

The papers, in Operating Session I, on "Problems of Sulphur Elimination" began with the "Desulphurization of Pig Iron." H. M. Griffith gave a preliminary report on plans that have been laid out by the Steel Co. of Canada, Ltd., at Hamilton, Ont., to obtain low sulphur pig iron for steel operations. Then followed a careful description by E. P. Best, A. M. Byers Co., Ambridge, Pa., of the preparation of pig iron, for subsequent use in wrought iron, by the use of fused sodium hydroxide which, it was stated, is 95 per cent effective in the removal of sulphur. In answer to questions from the floor, it was explained that this development is a continuation of the work begun by Edward B. Story in connection with his work as Chief Metallurgist of the A. M. Byers Co.

The most stimulating part of the session was by H. E. Warren, Jr., Director of Steel Production, Homestead Works, Carnegie-Illinois Steel Corp., in his paper on "Sulphur in Basic Iron and Steel." This paper gave an operating man's viewpoint of data taken from 24 casts from blast furnaces operated arbitrarily to produce high sulphur iron. The data included analysis of pig iron from top to bottom of transfer ladles, kish, slag, as well as steel samples at all stages of production in the open hearth, and molten metal temperatures at significant periods. It is significant to point out Mr. Warren's observation that high sulphur was not produced in pig iron carrying a manganese content over 2.80 per cent.

This factual report from an operating man's viewpoint set off a chain-reaction floor discussion that can be termed quite vigorous. However, when the different viewpoints were correlated it became obvious that the various participants in the discussion were basically in agreement, namely: the limits for sulphur specifications can be met provided the necessary penalty is taken, either by the blast furnace, or the open hearth.

A large part of the discussion centered around Mr. Warren's final chart showing the total amounts of sulphur brought into the furnace, but not necessarily the molten bath, by different fuels. As shown in the accompanying chart, the fuels, with one exception, carry more sulphur than the charged material which was given a theoretical content of 0.080 per cent sulphur. (Table 1.)

The interesting point about the Homestead operation is the cycling of the open hearth slag through the blast furnace, in order to pick up the otherwise wasted manganese, without the periodic breaks in cycling operations typical of other plants using similar operations.

"The Effect of Cold Charge and Additions on Sulphur Eliminations" were discussed in companion papers by W. H. Carpenter of Colorado Fuel & Iron Co., Pueblo, Colo., and A. H. Osborne of Armco Steel Corp., Middletown, Ohio. The latter gave strong emphasis to the importance of the rust content in the scrap used.

| Shop | Average Firing Rate | Lbs Sulphur Fired with Fuel: Per Hour | Lbs Sulphur Fired with Fuel: Per Net Ton Ingots | Lbs Sulphur Fired with Fuel: Per Heat | Lbs Sulphur Charged per Heat Using .080% S. Iron |
|---|---|---|---|---|---|
| O. H. # 5 | 450 gal. oil/hr. | 28.43 | 1.472 | 331 | 260 |
| O. H. # 3 | 50,000 cu. ft. coke gas/hr. | 40.44 | 7.264 | 540 | 72 |
| O. H. # 2 | 25,000 cu. ft. nat. gas/hr. | 0 | 0 | 0 | 60 |
| O. H. # 4 – 1 | 190 gal. tar/hr.<br>16,000 cu. ft. nat. gas/hr. | 15.01 | 1.447 | 171 | 132 |
| 2 | 200 gal. tar/hr.<br>30,000 cu. ft. coke oven gas/hr. | 40.08 | 4.277 | 505 | 132 |
| 3 | 190 gal. oil/hr.<br>16,000 cu. ft. nat. gas/hr. | 12.00 | +1.156 | 136 | 132 |
| 4 | 200 gal. oil/hr.<br>30,000 cu. ft. coke oven gas/hr. | 36.90 | +3.981 | 470 | 132 |
| 5 | 320 gal. tar/hr. | 25.31 | 2.37 | 280 | 132 |
| 6 | 320 gal. oil/hr. | 20.21 | 1.89 | 222 | 132 |

+ Assume production rate with oil is the same as tar.
% Sulphur in Fuel Oil — .79% by wt; Sp. Gr. = .959 A.P.I. @ 60° F = .06318# S/gal.
% Sulphur in Tar — .78% by wt; Sp. Gr. = 1.216 A.P.I. @ 60° F = .079104# S/gal.
$H_2S$ in Coke oven gas — 5.67 grains/cu. ft. = .80877 # $H_2S$/1000 cu. ft.
$H_2S$ in Natural Gas — Amount of Sulphur is negligible and can be overlooked.

**Table 1—Survey of Amount of Sulphur in Open Hearth Fuels.**

An interesting tabulation was the analyses for sulphur, of both the base metal and the accompanying rust in different forms of charged scrap.

| Type of Scrap | Per Cent Sulphur in Base Metal | Per Cent Sulphur in Rust |
|---|---|---|
| Mixed Steel | 0.029 —0.035 | 0.14 —0.35 |
| Sheet Scrap | 0.007 —0.018 | 0.31 —0.38 |
| Strip Scrap | 0.010 —0.024 | 0.23 —0.49 |
| Bloom Butts | 0.017 —0.027 | 0.32 —0.37 |

It was shown that an appreciable amount of sulphur may be carried into the furnace with rust as the carrier, or, in other words, the greater the degree of rust the higher the melt-in sulphur.

## use of oxygen

Operating Session II, held in the afternoon of Tuesday, April 19, included sectional reports on the "Use of Oxygen." These reports varied widely from enthusiasm in those districts where the intensive use of oxygen has proven advantageous to indifference in other regions where the more casual application of oxygen has not been productive of significant results. It was shown in the reports that oxygen has reached a "plateau" in its application to steel melting operations. Additional operating trials and further development await the increased availability of low purity oxygen on a tonnage basis.

Sectional Reports were also given in answer to questionnaires sent out on "What Is Being Done to Improve Scrap Quality and Better Prepare It for Charging." This was led by H. M. Parker, Superintendent, No. 2 Open Hearth, South Works, Carnegie-Illinois Steel Corp., who commented on the importance of cutting the pieces to sizes smaller than customary during the past in order to increase the density and thereby the capacity of the charge box.

The "Use of Blown Metal" was covered by S. J. Dougherty, Weirton Steel Co., on its use in stationary furnaces, and by S. J. Creswell, South Works, Carnegie-Illinois Steel Corp., who traced quite carefully its use in the tilting open hearth and its temporary deficiencies during the recent high demand for large tonnages of steel with low residual alloys.

The morning session of Wednesday, April 20, had for its highlight a presentation by B. M. Larsen, Supervisor of Process Research Metallurgy, U. S. Steel Corp., Kearney, N. J., on the "Mechanism of Foaming" which included "some speculative ideas with the hope of stimulating discussion and, possibly, some new ideas." The author's hope was fulfilled. To say that discussion was stimulated would be an understatement. The prepared comments from the rostrum and the impromptu discussions from the floor which were quite vigorous may be condensed to the brief summation in the statement that whenever an open hearth furnace operator is confronted with any sudden emergency, such as a foaming slag, it is necessary that he do something and do it quickly. He has not the time to stop and philosophize regarding the precisely correct action which he should take.

Also the morning of Wednesday, April 20, was the session on "Refractories and Masonry," carrying a careful review of "Basic Lined Furnaces."

In the first paper A. K. Moore reported on the all-basic furnace at the Hamilton, Ontario, plant of the Steel Co. of Canada, Ltd., who, having completed campaigns on five basic roofs, are now operating the sixth roof. After explaining the changing conditions of scrap and hot metal situations Mr. Moore presented as a summary a table giving the main points of production and cost of the first five roof series as well as the available data on the sixth roof now in operation. (See Table 2.)

The use of the oxygen lance during the sixth or current campaign, to promote lime boil or for rapid carbon reduction on high carbon heats, has brought out the ability of the basic roof to withstand high fuel rates with a resultant increase in the tons per hour spread between the all-basic and the silica furnaces.

## all-basic furnace

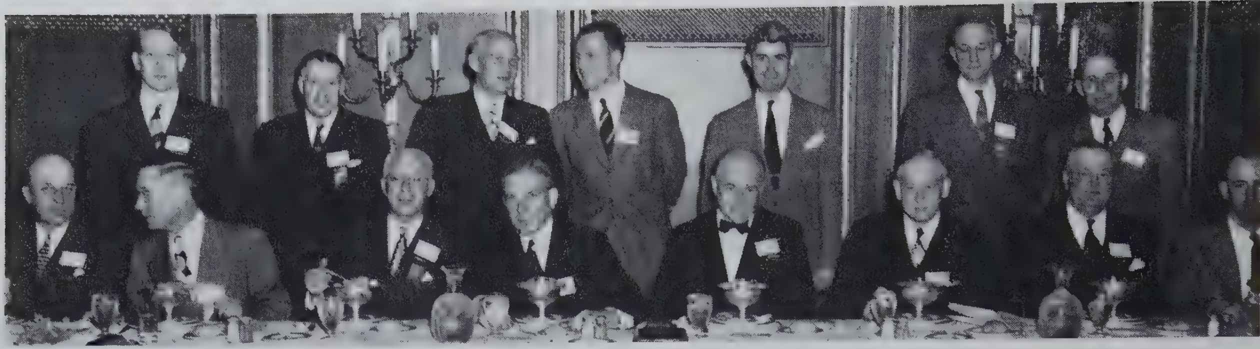
M. F. Yarotsky contributed in his report, presented in absentia, data on the all-basic furnace more recently installed at the South Works, Carnegie-Illinois. This paper covered in detail six points:

(1) *Stability of Basic Construction*—With the existing differential in cost, the performance of basic brick to be competitive with silica brick in the main roof of the open hearth must be improved, not only as to type and quality of refractory but also in the methods of construction.

(2) *Production*—Since conversion, the all-basic furnace has produced 13 per cent more than the furnace average of the shop.

| Roof No. | Total No. Heats | Ton. for Campaign | Avg. Ton. Sil, Fe | Dif. in Ton. | % Basic Above Si | Inc. Roof Cost /Ton | Inc. Fuel Cost /Ton | Total Inc. Cost /Ton | Dec. Front and Back-wall /Ton | Dec. Fluxes per Ton | Dec. Fix. Costs /Ton | Total Dec. Costs /Ton | Net Inc. C/T. | Net Dec. C/T. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 331 | 60625 | 52020 | 8605 | 16.5 | $.373 | $.099 | $.472 | 0 | $.006 | $.264 | $.270 | $.202 | .... |
| 2 | 381 | 69353 | 60024 | 9329 | 15.5 | .282 | .091 | .373 | $.030 | .006 | .220 | .256 | .117 | .... |
| 3 | 347 | 62186 | 55471 | 6715 | 12.1 | .215 | .090 | .305 | .025 | .009 | .200 | .234 | .071 | .... |
| 4 | 479 | 86700 | 78238 | 8462 | 10.8 | .126 | .080 | .206 | .025 | .006 | .180 | .211 | .... | $.005 |
| 5 | 465 | 83240 | 78214 | 5026 | 6.4 | .166 | .214 | .380 | 0 | .006 | .159 | .165 | .215 | .... |
| 6 | 117 | 21098 | 17569 | 3529 | 20.0 | Campaign not Completed | | | | .... | .... | .... | .... | .... |

Table 2—Production and Cost Data on Six Basic Furnace Roofs.



Speakers' Table at the Fellowship Dinner of the Open Hearth, Blast Furnace, Coke Oven and Raw Materials Annual Conference at the Palmer House, Chicago, April 19, 1949. Seated, left to right, W. S. Unger, secretary and T. L. Joseph, chairman, Blast Furnace, Coke Oven and Raw Materials Committee; C. D. King, chairman, ISD; Clarence B. Randall, president, Inland Steel Co., speaker; H. J. Watt, manager of sales, Western area, Carnegie-Illinois Steel Corp., toastmaster; E. G. Hill, acting chairman, NOHC; W. C. Kitto, past chairman, NOHC; T. B. Winkler, McKune Award winner. Standing, left to right, E. Kirkendall, sect.-treas. NOHC; A. P. Miller, ex-chairman, NOHC; E. L. Ramsey, ex-chairman, NOHC; F. G. Jaicks, Conference Award winner; Russel Fayles, Conference Award winner; L. R. Berner, acting chairman, Local Committee; E. J. Gardner, program chairman, Blast Furnace, Coke Oven and Raw Materials Committee.

(3) *Operating Delay*—No significant variance.

(4) *Fuel Economy*—Negative, due to the increase in heat losses due to radiation in basic brick causing increased firing rates.

(5) *Metallurgical Features*—No conclusive evidence of any advantage.

(6) *Overall Economy*—Negative, due to the cost of fuel and hot work repairs.

A characteristic factual report was presented by H. E. Warren, Jr., on the "Basic Ends" at the Open Hearth Department, Carnegie-Illinois Steel Corp., Homestead, Pa., with a detailed history of the original construction and the subsequent repairs. Mr. Warren concluded "that under the specific conditions investigated there is in the basic end construction much merit from the standpoint of economy, including the brick replacement; labor required to tear down and remove slag, and the cost of maintenance of tractor equipment. Because of shorter rebuild time there is an increase in available operating hours, especially important under full operating conditions."

The attention paid to this review on these papers was evidence of the interest taken in the large-scale production trials of basic brick in the open hearth furnace.

"Mixer Linings" were the subject of papers by Addison Maupin, on the use of special Sillimanite brick by Republic Steel Corp.'s Cleveland plant, and by F. A. Colledge, on Rammed Linings at Carnegie-Illinois Steel Corp.'s Munhall Plant.

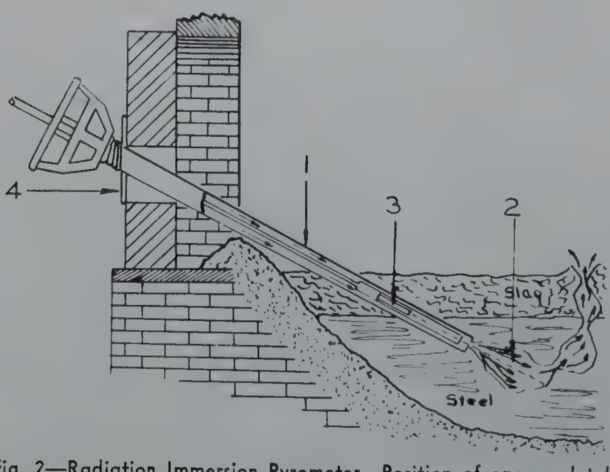



Fig. 2—Radiation Immersion Pyrometer. Position of open-end tube while a reading is being taken in the open hearth furnace. 1. Steel tube. 2. Cavity formed by compressed air. 3. Rayotube. 4. Wicket hole.

"Roof Life vs. Silica Brick Quality" was handled from two viewpoints. H. M. Kraner, Bethlehem Steel Co., discussed the quality of silica brick, while L. M. Wells, Carnegie-Illinois Steel Corp., emphasized that low alkali content is just as necessary as low alumina content in achieving the maximum benefit from silica brick.

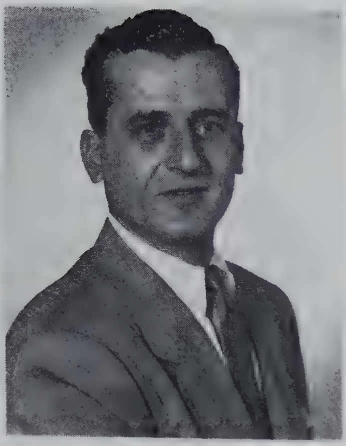
An important phase of the April 19 afternoon session, on "Cold Metal Operations and Basic Foundry Practice" was the subject of "Bath Temperature Pyrometers" as presented in papers by J. A. Warchol, Research Engineer, Lukens Steel Co., Coatesville, Pa., and W. D. Lawther, Chief Chemist, American Steel Foundries, East St. Louis, Ill. Both stressed the emphasis that has been put for many years on the importance of temperature in refining liquid steel in its relation to the various reactions of the molten bath, furnace life and, most important, the quality of the finished steel.

Mr. Warchol described the "Immersion Pyrometer," employing the radiation principle and its use in his plant. A very good description of the installation is given in the accompanying sketch. (Fig. 2.)

Mr. Lawther's paper likewise discussed the "air-purge radiation type immersion unit for the measurement of bath temperatures" and then went on to discuss the high accuracy of its reading, which is independent of "the melters' calibrated eye," and the relation of accurate readings to various quality requirements.

The interesting part of the production scale experiments with immersion pyrometers is the reliance put on them by the furnace operators in lieu of personal judgment or optical pyrometers, both of which are affected by varying light conditions.

The wide range of subjects covered at the Open Hearth Conference precludes any possibility of a resume of all papers presented, although each and every one covers an important part of the entire picture. The good attendance at the various sessions is indicative of the keen interest taken in the papers and the method of presentation by the individual speakers, all of whom sacrificed their own personal time to assemble the fundamental data so necessary to a logical presentation of their subjects.



JAMES A. STANGARONE

## Stangarone Becomes Advertising Manager

James A. Stangarone has been appointed advertising manager of JOURNAL OF METALS Technology · Practice. For the past eight years he has been actively engaged in publishing, advertising sales and promotion. Thus Mr. Stangarone will to a great extent relieve loyal committee members of the Metals Branch who have been working effectively to secure advertising. However it is to be hoped that members will continue their help in obtaining advertising and will provide Jim Stangarone with suggestions and introductions. Such cooperation will increase advertising revenue and will reduce the net cost of the JOURNAL OF METALS to members as well as permit some of the improvements members have requested.

**Please be sure to return the postcard recently mailed to you requesting information on your occupation so that we may have an accurate analysis of circulation with which to interest advertisers.**

Opportunity is taken here to announce the formation of an Editorial Advisory Committee for the JOURNAL OF METALS. The membership of this important policy determining committee is given on the masthead of this issue. Their job will be to try to provide readers with what they want most in their magazine from the funds available.

Speakers' table, Annual Luncheon, Blast Furnace, Coke Oven and Raw Materials Committee, Palmer House, Chicago, April 20, 1949. Seated, left to right, W. S. Unger, secretary; T. F. Plimpton, vice chairman and chairman-elect; T. L. Joseph, chairman; E. J. Gardner, chairman, program committee; C. D. King, chairman, ISD. Standing, left to right, K. C. McCutcheon, program committee; H. V. Lauer, vice chairman-elect; R. W. Campbell, chairman, paper committee and vice chairman-elect; C. L. Wyman, vice-chairman.

Annual Luncheon, Blast Furnace, Coke Oven and Raw Materials Committee, Palmer House, Chicago, April 20, 1949.

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Established as a Division April 26, 1918
(Bylaws published in the 1944 Transactions Volume of the Division)

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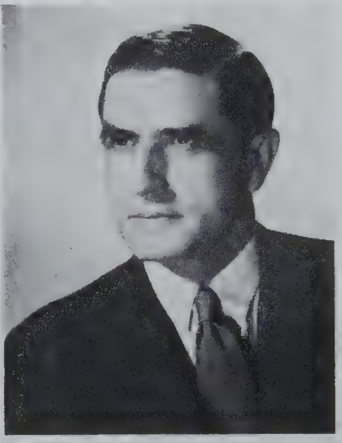

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Visitors and hosts at Chapman Valve Mfg. Co. at Indian Orchard, Mass. April 22, 1949.

# IMD Regional Conference at Springfield, Mass.

## *Technical Papers and Trips to Chapman Valve and American Bosch*

Some 120 registrants attended the Third Annual Institute of Metals Division, AIME, Regional Conference held in Springfield, Massachusetts, on April 22 and 23.

The morning of the first day was devoted to plant trips with a choice of visiting either the Chapman Valve Mfg. Co. or the American Bosch Corp. Both groups left the Sheraton Hotel by bus at 10 a.m. Those visiting the American Bosch Corp. saw the metallurgical laboratory, the heat treating and plating shops and were particularly interested in the injection pump assembly and automotive division assembly lines. Howard Boyer, chief met. and a very active member of the Conference Committee; Mr. Kiely, exec. asst. to the mgr. of engrg. and Mr. Woodbury, exec. asst. to the vice pres., acted as guides. Mr. Harris, vice pres. of production; Mr. Miller, mgr. of engrg. and Mr. Riddle, mgr. of ind. relations, joined the group at noon, when they were treated to a fine luncheon as guests of the American Bosch Corp.

The group visiting the Chapman Valve Mfg. Co. saw more valves, more sizes and types of valves and valves being made from a wider variety of materials than most had ever seen before. The larger cast iron and steel valves ranged up to 40 tons. Specialty valves included large valves shaped to interfere negligibly with the flow of liquid when open, valves to operate red hot at high steam or oil temperatures, and valves of various ferrous and nonferrous corrosion resistant materials. Visitors were particularly interested in watching stainless steel being welded on those surfaces and only those surfaces requiring extra protection. The surface was built up from wire welding rod and machined. The trip was well planned by George E. Fox, works mgr., and Vincent T. Malcolm, dir. of res., and the very effective general chairman of the Conference. Following the plant trip the visitors further enjoyed the good hospitality of the Chapman Valve Mfg. Co. as guests at luncheon.

The opening technical session was scheduled at 2 p.m. with four papers arranged by W. H. Sharp, session chairman. D. H. Thompson, American Brass Co., presented the first paper, coauthored by A. W. Tracy on "The Influence of Composition on the Stress Corrosion Cracking of Some Copper-base Alloys." The complete paper appears on page 100 of the Metals Transaction Section of the February issue, JOURNAL OF METALS and was presented at the Annual Meeting in San Francisco. Its presentation was repeated here since most Easterners, including the authors themselves, had not been able to attend the San Francisco meeting. In summarizing the laboratory experiments, Mr. Thompson said: "Season cracking is a corrosion phenomenon, accelerated by stress. Corrosion occurs because of the formation of a cell, the anode of which is an actively corroding area. In the tests reported, the addition of alloying elements to copper have caused grain boundaries to be anodic to grain bodies. The reason for this shaft in potential may be associated with a concentration of solute atoms at the grain boundary; or with lattice dislocations from the presence of these foreign atoms. It may also result from the formation of protective films on the surface of the metal, thus forming cathodic areas that increase the corrosion at boundaries. Any of these effects might be reversed as the concentration of alloying element is increased, as the minima in some of the curves indicate."

"Gaseous Fluxes for Brazing Steel" by A. P. Edson, D. G. Paquette, Hamilton Standard Propeller Div., United Aircraft Corp., and I. L. Newell, Henry Southern Engineering Co., was the second paper on the program. Basic requirements of fluxes in general were reviewed, including the reduction or dissolving of surface oxides without unduly attacking the metals themselves. Most fluxes were used as liquids, but the fact that they were difficult to remove in some applications after use and were more or less corrosive to the base metal, had lead to the development of gaseous fluxes. Hydrogen and carbon monoxide have been extensively used where the oxide is easily reduced, as in copper brazing of steel. Ethyl and methyl borate vapors have been used for torch brazing. Hydrogen chloride vapor will function, but in non-laboratory use the traces of moisture present permit corrosion of the steel being joined. Hydrogen fluoride would work, but ammonium fluoride, bifluoride and polyfluorides were simpler to handle and produced comparable results. Ammonium fluoborate

Visitors and hosts at the American Bosch Corp., Springfield, Mass., April 22, 1949.

proved to have superior fluxing activity. Boron trifluoride was the most satisfactory gaseous flux reported. It was less toxic than the fluorides, available in high pressure cylinders, did not sublime and clog exhaust lines from the brazing chamber, did not attack the steel surface, fluxed more effectively and produced the best joints. The speaker emphasized that gaseous fluxing was not a cure-all, that gaseous fluxing is relatively slow, extremely sensitive to contamination and more expensive, but for critical applications it may prove invaluable.

W. L. Finlay and E. L. Wemple, Remington Arms Co., presented the next paper entitled "Metallography and Properties of Commercially Pure Titanium" (See also page 6 of the January issue.) Two interesting metallographic facts were noted: Namely that titanium changes from hexagonal-close-packed to body-centered cubic above 885C and that titanium twins mechanically when deformed at room temperature. The latter required care in removing the effected surface immediately below the scratches produced in the early metallographic polishing steps before final polishing.

Titanium is intermediate between aluminum alloys and stainless steel in specific gravity, about equal to them on a strength-weight ratio, has a higher melting point than either, and has twice the annealed yield strength of 18-8.

An interesting conclusion to this paper was a list of possible applications for titanium as follows:

1. Airframe skins and structures where intermediate temperatures or corrosion problems are encountered.
2. Aircraft power plants where temperatures between 300F and 800F are involved.
3. Naval or marine applications in which the combination of superior corrosion resistance and light weight are important.
4. Industrial equipment in which titanium's particular corrosion resistance can be utilized.
5. Miscellaneous applications in which a combination of light weight, corrosion resistance, high strength and intermediate temperature properties are required.

The final paper "Solid Phase Bonding of Aluminum to Steel," by V. W. Cooke and A. Levy, Pratt & Whitney Aircraft Div., United Aircraft Corp., was truly an eye opener. As Dr. Kinzel commented to the authors, "Everyone knew it was impossible so you went ahead and did it." One of the chief precautions to a successful bond was to avoid a heavy oxide coating on the ferrous material. This could be done by using stainless steel or chromium plating the low alloy steels. After bonding a full solution treatment for the aluminum alloy was not permitted, since this combination of time and temperature permitted enough diffusion to build up a sufficiently thick intermetallic compound layer to be brittle. Bond strengths of from 20-50,000 psi tensile strength were possible and bonding could be accomplished at as low a temperature as 550F where little upsetting under the pressures used was noted. It is expected that this paper will appear in the JOURNAL OF METALS later this year.

The annual dinner started an enjoyable evening again this year. General Chairman Vincent Malcolm welcomed the guests and introduced the toastmaster, A. Dudley Bach, president, New England Metallurgical Co. As those who had heard him before knew, he kept the evening program lively and did an excellent job as toastmaster. Springfield's mayor, Daniel Brinton, was there to welcome the registrants. Dinner guests were also privileged to have John J. Duggan, president, Chapman Valve Mfg. Co. present to receive the thanks of those who visited his plant during the morning and to talk briefly to the group.

The principal talk of the evening, "Research, the Foundation of the Metals Industry in New England" was given by Dr. A. B. Kinzel, president, Union Carbide and Carbon Research Laboratories. So many Ph.D.'s had been introduced that he opened his talk by saying fellow members of the "meticallurgical fraternity." He gave an excellent and interesting presentation of the part played by research in opening new fields and in providing more jobs by expanding or creating new industries. Avoiding pleasant generalities, he gave specific examples applying to the New England area. Dinner guests were happily surprised to have the mayor stay for the principal speech, but then he was learning things about New England that might prove helpful the next time he spoke.

The final session of the meeting was a Seminar on High Temperature Materials Saturday morning. Norman Mochel, Westinghouse Electric Corp., and last year's Chairman of the Joint ASME and ASTM High Temperature Committee on the Effect of Temperature on the Properties of Metals, acted as Chairman of the seminar. The first paper on "Alloys for High Temperature Service" was an excellent review by R. H. Thielmann, Pratt & Whitney Div., United Aircraft Co. Sidney Low, Chapman Valve Mfg. Co., gave the second paper entitled "Sigma Phase in Cast Austenitic Steels." He presented some new ideas and x-ray diffraction evidence of the existence of the sigma phase after elevated temperature aging. An interesting discussion on interpretations followed.

"High Temperature Research" was the concluding paper by Ernest Robinson, General Electric Co. and the present chairman of the Joint High Temperature Committee. Discussion at this seminar was excellent, as it should have been, considering the talent present. Vincent Malcolm, general chairman of the conference, had been the first chairman of the Joint High Temperature Committee in 1924.

At the committee meeting which followed, Roger Sutton was elected chairman for the Fourth Conference and George Swift was reelected treasurer. Providence, Rhode Island, was selected as the location of the 1950 IMD New England Regional Conference.

# Metals Branch, S. Calif. Sect., AIME, Participates in Western Metals Congress

At right, James Kavenaugh, S. Calif. Metals Branch, Program Chairman, Western Metals Congress, AIME Participation; at left, Leo Schapiro, chairman, Metals Branch, S. Calif. Section.

The Metals Branch, Southern California Section, AIME, participated in the Western Metals Congress with three technical sessions comprising six papers. In the opening session, W. D. Briggs, chief chemist, Northrop Aircraft Co., reviewed the literature of hydrogen diffusion in steel and made a strong plea for a proper study of the application to practical cases of this widely discussed technical knowledge. Proclaiming hydrogen the scapegoat in most instances of embrittlement is not an adequate use of the knowledge of hydrogen diffusion. Industry is in dire need of a standard test that can establish beyond a doubt that hydrogen is the embrittling agent in failure experiences. Government specifications relating to embrittlement relieving treatment do not take cognizance of differences between hydrogen contents resulting from various industrial operations.

H. P. Nielsen, associate professor of mechanical engineering at the University of Southern California, described the degree of temper brittleness manifested by a Krupp analysis air hardening steel used for gun barrels. The loss of impact strength of samples tempered for various time periods in the 400-1000 F range was established as temper brittleness by the delineation of a precipitate in prior austenite grains by the use of a Zephiran chloride etchant. Fracture tests duplicating the impact tests manifested sufficient differences between embrittled and non-embrittled specimens to indicate that the lower cost fracture test may be an adequate substitute for the higher cost impact test in delineating the temperature range of temper embrittlement.

In the second session, conducted jointly with the American Foundrymen's Society, J. H. Berryman, technical sales, Air Reduction Sales Co., described steel making's latest tonnage-increase tool, "oxygen for combustion" and "oxygen for decarbonization." Oxygenated oil firing of open hearth furnaces yields maximum tonnage increase only when furnace charging and tapping keeps pace with the accelerated combustion rate. With oxygen consumption of 500-600 cu. ft. per ton for high hot metal charges and 1000-1200 cu. ft. for all cold charges, full furnace campaigns have shown production increases of 20 percent with fuel savings about 12 percent and no increase in refractory cost.

Decarbonization oxygen, substituted for "added ore," in the order of 50-150 cu. ft. per ton has effected production increases of 15-30 percent together with a 10 percent fuel savings and a substantial savings in refractory cost. Used also for temperature control, opening up of "flat heats" and activating sluggish lime boils, injected oxygen is being used in one shop as a tapping guide in place of final carbon analysis. Injected oxygen has also found wide acceptance in basic and acid electric furnace operation.

Dr. G. F. Found, manager, technical service and development, Magnesium Div., Dow Chemical Co., discussed the effects of grain size on the physical properties of high strength wrought magnesium alloys and illustrated with graphs and photographs the direct relationship between yield strength and grain size. The smaller grains give the higher strength values. Machinability as exemplified by the manufacture of print rolls was found to improve with a decrease in grain size. Other metallurgical characteristics were compared with strength properties. Dr. Pol Duwez, associate professor of Mechanical Engineering, California Institute of Technology, explained the fundamental principles which led to the modern development of the science of alloys, and showed that an understanding of metals depends upon a knowledge of three basic concepts: (a) the pattern or arrangement of atoms in a crystal; (b) electron configuration in the atom; and (c) atomic size. The notion of metallic bond was described and charts were presented to illustrate the application of these rules to common and uncommon alloys. An analysis of unknown alloys of titanium was projected. A special case of small atoms forming interstitial structures was discussed. The use of these concepts in the study of new alloys was emphasized.

Dr. J. T. Howe, head, Division of Metallurgy, Knolls Atomic Power Laboratory, outlined the metallurgical problems confronting the development of atomic energy, breaking them down into (a) reactor economy; (b) heat transfer; (c) stability and (d) fabrication. A fundamental knowledge of corrosion and diffusion of metals into metals is required before reactor economies may be accomplished. The central problem at present is connected with heat transfer and requires an understanding of corrosion-erosion, fatigue strength under thermal shock conditions and the effect of nuclear radiation on the properties of metals. A thorough knowledge of the physical and atomic characteristics of many metals under normal and abnormal conditions must be developed by joint efforts of physicists, chemists and metallurgists. Considerable data were presented on the properties of reactor materials.

LEO SCHAPIRO


# LETTERS TO THE EDITOR

## "Traces" Prevail in Many Fields

*Editor, Journal of Metals*
Dear Sir:

The paper of Dr. Frank A. Gilbert on metal traces in agriculture points up the fact that "traces" are important in many fields, including metals and alloys, catalysts, biology. In fact my Presidential address to the American Section of the Society of Chemical Industry in 1916 was entitled "The Importance of 'Impurities,'" and gave some of the information then available. Welsbach patented his gas mantle on the assumption that he was dealing with pure thoria; but improved methods of analysis later showed that his thoria contained the critical amount (1%) of ceria needed to get a bright light. The Courts sustained the patent, however, for Welsbach was dealing with "thoria" as *then* known commercially. Similarly, the solvent powers of "wood alcohol" differed from those of methanol, because the crude product contained ketones as impurity, a fact of which the Courts took notice.

In many, if not most cases, where minute traces of metals are effective biologically, the metals serve as prosthetic or activating groups in catalysts, which, in turn, produce effects quite out of proportion to their mass. Certain molds require at least 1 part of gallium in 40 millon for growth, and biotin is effective in 1 part in 400 billion. Oysters hatch to free-swimming larvae, which become "spats" only in the presence of traces of copper, as H. F. Prytherch found. In alloys and metals, trace substances may be adsorbed on the surfaces of growing crystals, and greatly affect the course of crystallization, and there is a large literature on this aspect of the effects of impurities and trace substances.

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## Health Hazards in Processing Beryllium

In your April number, page 285, there is an interesting paper on the "Beryllium-Iron System." In looking this over, I fail to find any caution as to the highly poisonous nature of beryllium, which in finely divided form can produce serious lung damage, as well as other harm. It seems to me that these facts should be called to the attention of your readers who might not have seen the medical and other literature bearing on this question.

JEROME ALEXANDER

(The editors are grateful to Mr. Alexander for his interesting comments on two phases of subject matter previously published in the JOURNAL OF METALS and are anxious to have readers note the following precautions prepared by Dr. Wolf.)

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The toxicity of beryllium is now well recognized. Although early toxicological investigations[1] did not illicit toxic responses in animals exposed to beryllium, subsequent industrial experience[2, 3] has demonstrated that beryllium compounds are highly toxic to man. More recently, the toxicity of beryllium has been demonstrated in animals.

Three types of beryllium poisoning have been described. Acute beryllium poisoning is a disease, primarily of the lungs, which resembles pneumonia and

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## SMELTS and SMILES

By Edgar Allen, Jr.


"Confidentially, he smelts!"

the type of acute poisoning which results from exposure to irritant gases such as phosgene and nitrous fumes. It has been shown[4] that this type of beryllium poisoning can result from single excessive exposures. Cases have occurred from the machining and welding of beryllium metal. To the best of our knowledge, no acute cases have resulted from the processing of beryllium alloys.

The course of acute beryllium poisoning is rapid. A high percentage of acute cases have been fatal, usually within two weeks after the onset of this disease. Cases which do not terminate fatally recover rapidly with no apparent permanent injury.

Chronic beryllium poisoning is an insidious disease which has been reported in the machining of beryllium metal and in the casting of beryllium copper. We know of no cases which can be identified with the processing of other beryllium alloys.

The principal manifestations of this disease are in the lungs, although other organs of the body are also affected. The onset of this disease may occur during the period of employment with beryllium compounds or up to several years after the cessation of beryllium exposure. The respiratory function is markedly impaired and there is a striking loss of weight. A relatively large percentage of these cases terminate fatally.

Skin lesions have been reported from contact with acid compounds of beryllium and from broken fluorescent lamps. The beryllium-containing phosphors which have been used in these lamps are believed responsible for the latter lesions. The skin manifestations have not been shown to have occurred in the processing of beryllium metal and its alloys.

Both the acute and chronic forms of beryllium poisoning result from inhalation of beryllium compounds. It is therefore of utmost important that all dust producing operations, however minimal the contamination may seem, should be properly ventilated. Because cases are known to have occurred among residents in the vicinity of beryllium processing plants, the effluent from exhaust systems should be filtered before discharge to the outside atmosphere. Meticulous housekeeping should be observed and vacuum cleaning employed in preference to sweeping. The exhaust from the vacuum cleaner should discharge into the outside air.

Air analyses in the breathing zone of exposed workmen are the best indication of the adequacy of control measures. Although there has been insufficient experience to justify any firm yardstick by which an exposure can be judged, most people who have investigated this disease believe that employees should not be exposed to concentrations greater than 2 micrograms of beryllium per cubic meter of air. Air samples can be collected by drawing a known volume of air through filter paper (Whatman No. 41). The beryllium content of the material collected can be assayed spectrographically.

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[1] Bulletin #181, U. S. Public Health Service.

[2] HARDY, H. L. and TABERSHAW, I. R.: Delayed chemical pneumonitis occurring in workers exposed to beryllium compounds. J. of Ind. Hyg & Tox., 28: 197, 1946.

[3] VAN ORDSTRAND, H. S. HUGHES, R., DeNADI, J. M. and CARMODY, M. G.: Beryllium poisoning. J.A.M.A., 129: 1084, 1945.

[4] EISENBUD, M. et al: Environmental studies in plants and laboratories using beryllium. J. Ind. Hyg & Tox., Sept. 1948.



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# W. H. Peirce Laboratory Dedicated

## H. W. McQuaid, Speaker

The new Peirce Memorial Laboratory of Metallurgy at Stevens Institute of Technology was dedicated May 12 in an impressive ceremony attended by representatives of metallurgical industries, technical societies, alumni and college officials. Dr. Alfred Bornemann, director of the Department of Metallurgy at the college, opened the dedication with a short address and introduced other participants.

The laboratory was established under a trust created by the late William H. Peirce, supplemented by contributions from the Stevens alumni. Mr. Peirce's achievements in metallurgy have been widely recognized. He was awarded the James Douglas Medal by the AIME for "distinguished achievement in nonferrous meallurgy." He was the inventor of methods of smelting and refining of copper, particularly in basic converting of copper matte to "blister" copper and the electrolytic refining of the resulting product.

He played an important part in the development of the Peirce-Smith basic lined converter which is recognized as one of the few fundamental advances in copper metallurgy. He also was influential in bringing about the step from hand-ladled furnaces carrying 15 tons to a charge, to erosive tapping into an intermediate ladle which has led to 300-ton charge furnaces and the removal at the rate of 60 tons an hour; and also for the introduction of the use of drums with blast furnace jackets so that cooling is done by evaporation rather than through the circulation of water.

For 43 years Mr. Peirce was associated with the Baltimore Copper Smelting and Rolling Co. His years of experience had taught him the great value of physical metallurgy in facilitating industrial production by the specification of metallic heat treatments which would improve the properties of a metal and make it easier to fabricate.

Mrs. William H. Peirce of Baltimore, Md., widow of the distinguished metallurgist for whom the new laboratory was named, unveiled a portrait of Mr. Peirce. The portrait will hang in the stairwell on the second floor of the laboratory.

In the evening a lecture on "The Metallurgical Economics of the Manufacture and Uses of Steel" was given by Harry W. McQuaid, steel consultant of Cleveland. His theme was: "Good Enough is Best." If it isn't good enough one cannot stay in business and if it were better than necessary money is being wasted.

## Two Bibliographies

A bibliography on Precision Investment Casting by the Lost Wax Process has been compiled by the Engineering Societies Library, 29 W. Thirty-ninth St., New York 18, priced at $2.50.

A bibliography on industrial uses of radioactive tracers is now available without charge from Arthur D. Little, Inc., Cambridge 42, Mass.

# Further Consideration Given by Board to Report of Democratization Committee

Chief topics for discussion at the meeting of the Board of Directors, AIME, in New York on Wednesday, April 20, were the report of the Committee on Democratization and the forthcoming referendum on increased dues. Eighteen Directors, including two alternates, spent 5½ hours in their deliberations, which started with a luncheon meeting at the Engineers' Club, and continued in the Board room at Institute headquarters. President Young presided, with the following directors in attendance: Messrs. Bowles, Daveler, Elkins, Head, Kinzel, Kraft, Meyerhoff, Millikan, Peirce, Schumacher, Suman, Swift, Weed, Wrather, and Fletcher. Mr. Lovejoy acted as alternate for Mr. Watson and Mr. Work substituted for Mr. King.

The essential points made by the Committee on Democratization were reported in the March and April issues of the AIME journals. Mr. Gillson reviewed the report further, emphasizing that the Committee would be satisfied if the spirit of its report were accepted; for the time being, at least, it realized that certain of its suggestions, such as greatly increased traveling by the Secretary, a field secretary for the Mining Branch, and paid expenses of two Local Section delegates to three meetings a year, would be more costly than the Institute would be justified in undertaking. The Board was especially interested in the plan for a more formal organization of the Section delegates' group, and asked the Committee to work up a specific plan for presentation at the September meeting of the Board. There was some discussion as to the desirability of having fewer meetings of the Board, but making them more important, with carefully prepared agenda; it was thought that this would not be opposed to the idea of democratization. The Petroleum Branch reported its feeling that extensive trips into the field by the Secretary should not be necessary if he kept in close touch with the Branch executive committees, who would in turn, keep themselves fully informed of the feeling of the membership at large. The Branch also favored an increased number of younger men on the Board.

As to the progress of the movement to increase dues, approval was voted of the statement appearing over President Young's signature in the May issues of the journals. This was supported by separate editorial appeals in the three journals and mimeographed data prepared by the Secretary's office and distributed to all Directors and Local Section Chairmen. Considerable discussion arose as to the form of ballot for the referendum, and it was finally decided that this should take the form of a postal card which would be signed by the voter, who would not only indicate his approval or disapproval of the proposed increase, but would indicate his Branch affiliation. A reprint of President Young's statement would accompany the ballot. The postal card would be stamped and self-addressed to the Institute, and would be mailed on or about May 20 to all paid-up AIME members in the United States, Can-

ada, and Mexico, returnable by June 10, so that the results can be reported by officially appointed tellers, representing each Branch, at the June 15 meeting of the Board. The form of referendum ballot is not specifically stated in the bylaws but counsel advised that the proposed postal card meets the requirements for a "letter ballot."

### deficit to decrease in 1949

Based on operations for the first quarter, the final budget for 1949, as offered by Mr. Daveler, shows income at $380,350 compared with total expenditures of $437,479, or a deficit of $57,129, to be in part offset by voluntary contributions of $8,500, or a net estimated deficit for the year of $48,629. This would compare with the deficit of $82,000 suffered in 1948. The reduction in the deficit is almost exactly counterbalanced by the expected increase in advertising revenue in 1949 from the three new journals. Details of the budget, which this year for the first time is apportioned to the three Branches, were offered for discussion by the Board. The paid membership is divided approximately in the ratio of 52 percent for the Mining Branch, and 24 percent each for the Metals and Petroleum Branches. Allocating income and expenses to Branches, on the basis of information supplied by members, the deficit for the Metals Branch in 1949 is estimated at $55,122 and for the Petroleum Branch $17,161, whereas the Mining Branch would show a surplus of $23,754.

In view of the fact that many 1948 publications are out of print, the Board voted to allow a credit of $5 to all members in the United States who pay up their dues for 1948 and who cannot be supplied with one or more requested publications. In view of the further difficulty that some foreign members have had in securing American dollars, it was further voted to remit the entire amount of 1948 dues to those foreign members now in arrears for 1948 and 1949 dues. Also, the time was extended to Dec. 31, 1949, in which Junior Members of ten years' standing may change their status to Member or Associate Member without payment of an initiation fee: the date had previously been set at July 1, 1949.

Approval was voted to recommend to the Engineering Foundation that grants be made for certain research projects as follows: $2,500 for Project 97, Diffusion in Steel, by Morris Cohen; $3,000 for Project 98, Mechanical Properties of Binary Alloyed Ferrites at Low Temperatures, by R. M. Brick; and $1,000 for a new project in the field of comminution, by A. Kenneth Schellinger.

### 1951 annual meeting in St. Louis

Formal acceptance was voted of the invitation of the St. Louis Section to hold the 1951 Annual Meeting of the AIME in St. Louis, which is probably the most centrally situated city in which an Annual Meeting can be held for the convenience of AIME members. The 1950 Annual Meeting will be held at the Hotel Statler in New York, Feb. 12-16. No decision has yet been made as to the scene of the Fall Meeting of the AIME in 1950; it will be impractical to hold it in New Orleans as suggested.

Erle V. Daveler was appointed to represent the Institute on the John Fritz Medal Board of Award succeeding Clyde Williams, resigned. Fred Searls, Jr., was named to succeed H. M. Lavender as chairman of the Saunders Mining Medal Committee, and H. L. Roscoe was named to take Mr. Lavender's place as a committee member. Oliver C. Ralston was reappointed as an AIME representative on the National Research Council. Albert M. Portevin was named to represent the AIME at the centenary celebration of the French Society of Metallurgy in Paris next October.

The Cornell Metallurgy Society, at Cornell University, was formally recognized as an Affiliated Student Society, AIME. Selection of James A. Stangarone as advertising manager of the *Journal of Metals* was reported.

## Print Orders for Journals

Institute headquarters was faced with an important problem last December when it became necessary to decide on how many copies of each of the three journals to print, with no knowledge of what the wishes of the members would be. We wanted stocks to be adequate to supply the demand, but did not wish to waste money in printing journals for which there was no need. The print orders for the January issues were finally set at 11,500 for *Mining Engineering*, 6700 for the *Journal of Metals*, and 5500 for the *Journal of Petroleum Technology*. In the light of subsequent information only slight changes had to be made in succeeding issues: 10,800, 6700, and 5400 respectively. All issues of each magazine could be supplied up to May 1 except the January issue of the *Journal of Petroleum Technology*.

## Progress of Publication of AIME Volumes

In the December issue of *Mining and Metallurgy*, page 686, was published a list of the volumes whose publication was expected in 1949 and the terms under which members could secure them. The expected dates of publication of these volumes are:

No. 175 Institute of Metals Division. May.

No. 176 Iron and Steel Division. August.

No. 177 Coal Division. August.

No. 178 Mining Geology. May.

No. 179 Petroleum Development and Technology. August.

No. 180 Institute of Metals Division. October.

No. 181 Metal Mining, etc. October.

No. 182 Nonferrous Smelting and Refining. October.

No. 183 Minerals Beneficiation. November.

Open Hearth Proceedings. November.

Blast Furnace Proceedings. November.

Electric Furnace Proceedings. September.

Rod and Wire Symposium. August.

Statistics of Oil and Gas. August.

Industrial Minerals and Rocks. 2d ed. August.

Berwerk—und Probierbuchlein. Now available. $3 members; $5 nonmembers.

Conservation of Petroleum. No date set.

Coal Preparation. Revised edition authorized but no date set.

This is Columbus, home of Ohio State, the Capital, Battelle Memorial Institute, and the AIME Fall Meeting.

# AIME General Meeting Set for September

The date has been set, and tentative plans prepared, for the AIME Fall Meeting, to be held this year in Columbus, Ohio. The kickoff, and it will be a real kickoff, is set for Saturday, Sept. 24, which day will be spent at the Ohio State–Missouri football game in Columbus. Registration will be the following day, and Monday will see the beginning of a six-day round of technical sessions, inspection trips, and executive conferences. The meeting will close on Oct. 1, just in time for the Ohio State–Indiana football game.

Twenty-one hours of technical sessions will be held on Monday, Tuesday, Wednesday, and Friday, but Thursday will be reserved for inspection trips which will include the National Electric Coil Co., Jeffrey Mfg. Co., and the Battelle Memorial Institute. Programs are being planned by most of the Divisions of the Institute. A cocktail party and banquet will also be held during this busy week. In addition, the Southern Ohio Section of the Open Hearth Committee, AIME, will meet on Friday, Sept. 30, for technical sessions, luncheon, and an evening banquet. The Open Hearth group's Executive Committee will also meet on the last day of the Meeting, and then be off to see the closing gridiron tussle.

The Neil House in Columbus will be headquarters for this mid-year general meeting, and those who are planning to attend can write Hugo E. Johnson at the Battelle Institute for further details.

## AIME Research Grants Continue

Four AIME research projects, dealing with diffusion of steel; alloys of iron research; basic open hearth steelmaking; and the behavior of metals during hot-working, will continue to receive support this year from the Engineering Foundation, the research department of United Engineering Trustees, Inc., for the Founder Societies, a group founded thirty-five years ago for the ASCE, ASME, AIEE, and AIME.

Although the Foundation's available funds are now only $24,353 or less than half what they were a year ago, that amount will provide grants for a total of thirteen research projects this year. Contributions are made primarily to support studies and analyses necessary to organize projects to a point where they can be supported from other sources. Eighteen such projects were supported during the past year.

## EJC Survey on Engineering Employment and Salaries

The General Survey Committee of the Engineers Joint Council, which is composed of representatives of the major engineering societies, has recently concluded a survey of representative industrial companies and governmental agencies concerning their 1949 employment programs for engineering graduates. Of 500 questionnaires sent out late in January, 193 had been returned early in May, but none of these were from strictly mining companies.

Excluding a few small organizations providing incomplete data, there were 162 industrial companies and 31 governmental agencies in this group with over 4 million employes, of whom 89,000 were engineering graduates, or a third of some 265,000 such graduates in the country.

These organizations reported that they had hired 10,390 inexperienced engineering graduates in 1948 and estimated that they would hire 8174, or some 21% less in 1949. For the industrial companies, the decrease was 26% to a total of 5695; for the governmental agencies, 9% to one of 2479. Agencies of the state governments actually expected a substantial increase.

On the basis of the starting rates reported, 25% of these men at the Bachelors' level would receive a starting rate of $275 per month or more, 50% one of $255 or more (the so-called median rate) and 75% one of $250 or more.

The median rates reported by organizations, without regard to the numbers of men to be employed, were $255 for Bachelors', $300 for Masters', and $375 for Doctors' degrees.

A median monthly increase of $30 is given by the end of the first year by the organizations in this group. 45% of them give this total at one time, 49% in two installments, and the remainder in three or four installments.

In order to secure some indication of the recent trend in salaries of engineering graduates with experience, the survey also requested data for those 10 years beyond their Bachelors' degrees late in 1946 and those who were 10 years out late in 1948. Only 82 organizations provided these data and, to some extent, they represent estimates rather than exact figures. For 1511 graduates 10 years out in 1946, the median monthly salary was $375 and for 1431 who were 10 years out in 1948 it was $450, or 20% more. The 1946 figure corresponds closely with that secured by a survey of individual engineering society members at that time, and on that basis the current data for both years may be regarded as reasonably reliable.

## Calendar of Coming Meetings

**JUNE**

2 **Reno Branch, Nevada Section, AIME.**
3 **Columbia Section, AIME.**
3-4 **Central Appalachian Section, AIME, spring meeting, Blacksburg, Va.**
5-10 SAE, summer meeting, French Lick, Ind.
8 **El Paso Metals Section, AIME.**
13-15 15th National Applied Mechanics Conference, University of Michigan, Ann Arbor.
13-15 Annual convention, Idaho Mining Association, Sun Valley.
14 **East Texas Section, AIME.**
15 **Southwest Texas Section, AIME.**
16 **Carlsbad Potash Section, AIME.**
16 Engineering Foundation, 29 W. 39 St., New York City.
June 27-July 1 ASTM, 52nd annual meeting, Chalfonte-Haddon Hall, Atlantic City, N. J.
20-22 American Society of Heating and Ventilating Engineers, semi-annual meeting, Minneapolis, Minn.
20-24 AIEE, summer general meeting, New Ocean House, Swampscott, Mass.
20-24 American Society for Engineering Education, RPI, Troy, N. Y.
21 **Gulf Coast Section, AIME.**
25-26 American Iron and Steel Institute, general meeting, N. Y. C.
27-30 ASME, semi-annual meeting, San Francisco.
27 **Alaska Section, AIME.**
28 **Montana Section, AIME.**
29 **Pennsylvania - Anthracite Section, AIME, summer meeting Split Rock Lodge, Pocono Mountains.**

**JULY**

9-23 Fourth Empire Mining and Metallurgical Congress, Great Britain.
13-15 American Society of Civil Engineers, summer convention, Mexico City.
15-24 Pan-American Engineering Congress, Rio de Janeiro.

**AUGUST**

23-26 AIEE Pacific general meeting, Fairmont Hotel, San Francisco.
26-Sept. 10 Engineering & Mining Exhibition, London, England.

**SEPTEMBER**

25-28 **Mid-year Meeting, AIME, Neil House, Columbus, Ohio.**
25-28 American Mining Congress, Western fall meeting, Spokane.
29-30 ASME, fall meeting, Erie, Pa.
29-Oct. 1 Colorado School of Mines, 75th anniversary celebration.
**Sept. 30-Oct. 1 Southern Ohio Section of Open Hearth Committee, AIME, fall meeting, Deshler-Wallick Hotel, Columbus.**

**OCTOBER**

5-7 **Petroleum Branch, AIME, fall meeting, Plaza Hotel, San Antonio, Texas.**
13-14 Texas Mid-Continent Oil and Gas Association, annual meeting, Rice Hotel, Houston.
14 **Eastern Section, Open Hearth Committee, Iron and Steel Division, annual all-day fall meeting, Warwick Hotel, Philadelphia.**
14 **Southwestern Section, Open Hearth Committee, Iron and Steel Division, Kansas City, Mo.**
17-19 **Institute of Metals Division, AIME, fall meeting, Allerton Hotel, Cleveland.**
17-23 AIEE, 1949 Mid-West meeting, Netherland Plaza, Cincinnati.
20-21 **Petroleum Branch, AIME, Elks Club, Los Angeles.**
24-28 Thirty-seventh National Safety Congress and Exposition, Chicago.
26-27 **Joint Fuels Conference, ASME-AIME, French Lick Springs Hotel, French Lick, Ind.**
28 **Pittsburgh Section of Open Hearth Committee and Pittsburgh Section, AIME, annual fall meeting, William Penn Hotel, Pittsburgh.**
28-29 ECPD, annual meeting, Edgewater Beach Hotel, Chicago.

**NOVEMBER**

1-5 Pacific Chemical Exposition, California Section, American Chemical Society, San Francisco Civic Auditorium.
2-4 American Society of Civil Engineers, fall meeting, Washington, D. C.
7-10 AIChE, annual meeting, Pittsburgh, Pa.
9-11 **Industrial Minerals Division, AIME, Tampa, Fla.**
12-14 Geological Society of America, annual meeting, Hotel Cortez, El Paso.

**DECEMBER**

8-10 **Seventh Annual Conference, Electric Furnace Steel Committee, Iron and Steel Division, AIME, Hotel William Penn, Pittsburgh.**

**JANUARY 1950**

18-20 American Society of Civil Engineers, annual meeting, New York.
30 AIEE, winter meeting, New York.

**FEBRUARY 1950**

12-16 **Annual Meeting, AIME, Statler (Pennsylvania) Hotel, New York City.**

**APRIL 1950**

10-12 **Open Hearth Conference, and Blast Furnace, Coke Oven and Raw Materials Conference, Netherland Plaza Hotel, Cincinnati.**
19-21 American Society of Civil Engineers, spring meeting, Los Angeles.

**NOVEMBER 1950**

16-18 Geological Society of America, annual meeting, Hotel Statler, Washington, D. C.

**DECEMBER 1950**

7-9 **Eighth Annual Conference, Electric Furnace Steel Committee, Iron and Steel Division, AIME, Hotel William Penn, Pittsburgh.**

## If You Are Visiting Dayton

AIME members visiting Dayton, Ohio, are cordially invited to make use of the facilities of the Engineers' Club of Dayton, 112 E. Monument Ave., one block from the downtown business district. A guest card good for two weeks will be provided upon proper identification. Sleeping facilities are not available, but regular luncheons are served, a reading and billiard room is provided, and there is an excellent library of 10,000 volumes, with 100 periodicals received. William Siler is manager.

# What Went on at Recent Local Section Meetings

| SECTION | DATE | PLACE | PRESIDING OFFICER | ATTENDANCE | SPEAKER, AFFILIATION, AND SUBJECT |
|---|---|---|---|---|---|
| Boston | April 4 | MIT | George P. Swift | 146 | Clifford L. Curan, E. B. Badger and Son" s'An Engineer Views the U. S. S. R." |
| Carlsbad Potash | Mar. 24 | Carlsbad | J. P. Smith | 69 | C. P. Theis, New Mexico state geologist, on ground water. |
| Carlsbad Potash | April 21 | Carlsbad | J. P. Smith | 57 | E. F. Bunning, Central States Cooperative, on potash's use in fertilizers. |
| Carlsbad Potash | April 23 | Carlsbad | J. P. Smith | 146 | Annual spring dance. |
| Chicago | April 6 | Chicago Bar Association | T. S. Washburn | 83 | J. S. Smart, Jr., American Smelting and Refining Co., on ASARCO continuous casting process. |
| Cleveland | | Cleveland | | | Harold Hunsicker, Aluminum Co. of America, on precipitation hardening of aluminum alloys. |
| Cleveland | April 14 | University Club | | 22 | Dinner meeting. John Love, business analyst, Cleveland Press, on aspects of the economic landscape. |
| Columbia | April 1 | Spokane, Idaho | Howard P. Sherman | 61 | Robert D. Dallwo, attorney, on Communist technique and strategy. |
| Connecticut | April 13 | Bridgeport | H. L. Burghoff | 58 | A. D. Eplett, Manning, Maxwell and Moore, "Technological Observations in Postwar Germany." |
| Delta, Mississippi Subsection | April 21 | Laurel, Miss. | R. E. France | 82 | Walter F. Rogus, Gulf Oil Corp., on condensate well corrosion. E. N. Dunlap, California Research Corp., on AIME Annual Meeting. |
| Detroit | April 18 | Detroit | Eric Weinman | | W. L. Grube, General Motors Corp., on the electron microscope as a metallurgical tool. |
| El Paso Metals | April 13 | Texas College of Mines | Jack Despins | 38 | Baxter Polk, Texas College of Mines and Metallurgy, on the library for student and professional engineers. |
| Lehigh Valley | Mar. 25 | Bethlehem | F. E. Van Voris | 103 | Bruce S. Old, Arthur D. Little, Inc., on radioactive tracers in metallurgy and coke production. A. M. Gaudin, MIT, on radioactive tracers in mineral engineering. |
| Montana | Mar. 29 | School of Mines, Butte | Hollis McCrea | 130 | S. P. Nile, Montana School of Mines, on radioactivity. |
| Montana | April 26 | Anaconda Copper M. Corp. | | | Visit to Anaconda ferromanganese plant. R. H. Townsend, superintendent of zinc roasters, on ferromanganese operations. |
| New York | Mar. 10 | Mining Club | Thomas G. Moore | 69 | Claude A. Williams, President, Transcontinental Gas Pipe Line Corp., on natural gas. |
| New York | April 13 | Mining Club | T. B. Counselman | 87 | J. A. Retty, chief geologist, Labrador Mining and Exploration Co., on the Hollinger-Hanna Iron Ore development in New Quebec and Labrador. |
| Nevada, Reno Branch | Feb. 3 | Reno | L. D. Gordon | | Silas E. Ross, Chairman, Board of Regents, University of Nevada, on The Board of Regents and the Law. |
| Nevada, Reno Branch | May 5 | Reno | A. C. Johnson | 44 | Business meeting. Mackay School of Mines Day. |
| North Pacific | April 21 | Seattle | Kenneth Anderson | 52 | Field trip, Boeing Airplane Co. |
| Pennsylvania-Anthracite | April 22 | Altamont Hotel, Hazelton | Harry Otto | | Spring meeting. S. H. Ash, chief, Safety Branch, U. S. Bureau of Mines, "Anthracite Flood-Prevention Project." |
| St. Louis | Jan. 21 | Hotel York | Herbert A. Franke | 70 | Davis Read, chief engineer, West Kentucky Coal Co., on Coal Mine Mechanization. C. E. Davis, Goodyear Rubber Co., comments on film, "The Way Out." |
| St. Louis | Mar. 18 | Hotel York | Herbert A. Franke | 36 | Fred B. Loomis, Shell Oil Co., on oil exploration. Paper prepared by Ernest G. Robinson. |
| St. Louis | April 22 | Hotel York | | | J. G. Evans, Gardner-Denver Co., motion pictures taken in South Africa. |
| San Francisco | April 13 | Engineers Club | E. H. Wisser | 39 | James T. Kemp, American Brass Co., on Cornish mine pumping engines. |
| San Francisco | Mar. 9 | Engineers Club | E. H. Wisser | 84 | Edward Morris. Movies on California's gold mines. |
| Southwestern New Mexico | Mar. 16 | Bayard | Joseph H. Taylor | 27 | W. H. Goodrich and W. R. Storms. Reports on AIME Annual Meeting. |
| Southwestern New Mexico | April 13 | Bayard | Joseph H. Taylor | 61 | E. A. Slover, Chino Mines Division, Kennecott Copper Corp., on practices at Hurley copper smelter. E. M. Tittmann, American Smelting & Refining Co., "El Paso Zinc Fuming Plant." |
| Ohio Valley | April 11 | Columbus | William Mueller | 40 | William Mueller, Department of Metallurgy Ohio State University, delegates report on annual meeting. Hugo Johnson, Battelle Memorial Institute, explanation of new Section by-laws and discussion of plans for mid-year or Regional meeting. |

# THE DRIFT OF THINGS

. . . as followed by EDWARD H. ROBIE

## The Peak Is Passed

At last the postwar boom in metal prices has ended, and some mining companies, operating high-cost properties, will now have to curtail or close down. Copper at 23½¢ was high but not to be compared with lead at 21½¢, so the price of the former offered more resistance to decline, and began with but a slight shading by one seller. Lead, on the other hand took a headlong tumble, in less than a month, from 21½¢ to 16¢, and then dropped still further, to 14¢, by the middle of May. Zinc never got up to the price of lead, though before the war it ruled somewhat higher. From a high of 17½¢ it had dropped to 14¢ in mid-May. Copper was 18¢.

The high prices had the normal effect of stimulating an enormous amount of exploration and development work, and plant extensions. In a large number of instances the geologists have been successful, as Donald M. Davidson showed in his most interesting article in the March *Mining Engineering*. Important new metal mines are springing up all over the world. Unfortunately most of them will come into production when the demand has quieted down, and their added pressure on the market will drive prices still lower. Mineral production cannot respond to prices as quickly as can that of many other commodities.

Coal and oil, likewise, are in ample supply, but the price of oil never boomed like the prices of the nonferrous metals, so has better resisted a decline. Coal has been more nearly in line with the cost of production, so until wages come down, which we understand Mr. Lewis is not planning, no great cuts in price are likely there.

Though the metal mines will get less for their product from now on, there will be compensations. Labor will be easier to get and will work harder, and the cost of supplies will be less.

## Good Times or Bad Times?

Our electrician, whom we called in the other day only to find a blown fuse that we did not have intelligence enough to find ourselves, told us that now he is really glad to have work, and no longer is trying to escape it. He says helpers are much easier to get too, and what's more they work instead of sitting around talking. This condition seems to be returning in all fields of activity. Even in professional mining, more people are looking for jobs, and less employers are calling for men. If not carried too far, the condition is a healthy one, and makes for better work habits. It will, of itself, reduce the number of jobs, however, for if everybody works ten per cent harder, then ten per cent less people will be needed to do the country's work. A diligent person, can, we suspect, still find something to do.

## Buyers' Market for Graduates, Too

Engineering graduates this year are not able to sit back and take their choice of several offered jobs, which is the condition that has existed in recent years. The supply of graduates is increasing and the demand, owing to the recession in industrial activity, is decreasing. Many graduates that expected employers to come after them have found that they must go out and rustle jobs for themselves.

Employers tells us that where half the offers they made to students have been rejected in the last few years, the proportion is now only about 25 percent, and that most of this 25 percent is made up of men who plan to take graduate work or who have decided to work in local areas close to their homes. The increasing proportion of students that plan to take graduate work, in part because they cannot get attractive jobs, will make it just that much harder for those with Bachelors' degrees to get jobs in the years to come.

Also, we learn from employers that the character of the present crop of graduates has changed. Heretofore, most of them had had actual military service, and many had held commissions—in general a most desirable group, earnest, mature boys, trained in administration and supervision as well as in their technical specialty. Now, they are classifiable for the most part into two groups—(1) really outstanding boys and (2) graduates that should never have gotten that far in their schooling, the "4F's in the head," who went to college because there was nothing else to do and they could do so at the taxpayers' expense. They have not had much military experience—mostly just in camps. Even with a degree they will have rather hard sledding this year. The first group, however, the cream of the crop, should have no particular difficulty locating a satisfactory job even though they may have to go after it instead of it coming to them.

## Gold Output Still Lags

U. S. Gold output last year was valued at 73 million dollars—just about half what it was before the war. The picture for the gold mines, however, is not as bright even as that might indicate, for most of the gold is obtained as a by-product, and would be produced whatever the price. Homestake is about the only straight gold mine of any importance left in the country. Canada has more gold mines by far; its output last year got back up to 123 million dollars, compared with 143 million in 1937. The freer labor supply and the current reductions in the price of supplies will redound to the advantage of the gold mines but it will take a real depression to make them prosperous. That is, unless the Government decides on what seems to us the sensible course of letting the gold miners sell their product freely for whatever it will bring. Certainly less than a hundred million dollars' worth of gold exported from the country in a year will not upset the international monetary commission.

Before we leave the subject of gold we might repeat an advertisement that the *New York Herald Tribune* reprints from an issue published 100 years ago: "Seekers after gold in the rivers and streams of California will need a suit of India-rubber to protect them from wet in their researches. Complete outfits of this material, coats, caps, boots, pantaloons with boots attached, camp blankets, life preservers, canteens, pails for collecting the gold &c. &c. for sale to enterprising adventurers at low prices by Ellis Tompkins & Co., New India-Rubber Warehouse, 28 John St." The pails for collecting the gold are now but rarely used.

## $5-a-Ton Oxygen

Metallurgists have been using more oxygen in the last decade or so than ever before. Compared with air it speeds up reactions and thus gives added capacity. A considerable fillip to this use may result if its cost can be cut by any such figure as is indicated by news of a plant in Texas built by Dresser Industries. This plant is said to have attained an output of more than 175 tons of 90-95% oxygen a day at a cost of only $5 per ton. Although this is somewhat lower in grade than the 99% oxygen ordinarily used in large quantities, the cost is only about a tenth as much. The difference in grade should not be of any particular importance in most metallurgical processes, but any such difference in cost should open up an enormous new field of application.

We have not read the details of the new process other than that it depends on a low-pressure self-contained cycle, using only cooling water and natural gas for fuel. Air is compressed to 85 lb, and then cooled by expansion and self-refrigeration. Carbon dioxide and other impurities are removed by deposition on special aluminum fin-tube exchangers, and the oxygen and nitrogen separated in aluminum fractionating columns.

## Scientific vs Legal Minerals

Down in Texas, Mrs. Emilie Heinat had willed surface rights to her 400-acre farm to a daughter, and the mineral rights to trustees for all of her children. When it was found that limestone could be produced commercially on the property, those to whom the mineral rights had been willed sued for possession of the property. The trial court held that limestone is a mineral, so the mineral owners should have the farm. The Court of Civil Appeals disagreed, and the Texas Supreme Court upheld the appeal. The interpretation of mineral rights was given by Associate Justice Smedley as follows:

"Substances such as sand, gravel, and limestone are not minerals within the ordinary and natural meaning of the word unless they are rare and exceptional in character, or possess a peculiar property giving them special value, as for example sand that is valuable for making glass, and limestone of such quality that it may be profitably manufactured into cement. Such substances, when they are useful only for building and road-making purposes, are not regarded as minerals in the generally accepted meaning of the word."

So, according to the newspaper report, "Limestone is not a legal mineral, although it may be a scientific mineral"! This is just so that our readers will be informed of the distinction, should they ever be asked.

## An Apposite Title

Three years ago we suggested that the title "Honorable" might better be applied to engineers than to lawyers and politicians. There was no apparent stampede to adopt our excellent suggestion, but we note with approval that the seed we sowed at that time has finally sprouted. In its announcement of "National President's Night" on May 2 the Pittsburgh Section of the AIME offers an illustrated talk by

The Honorable Lewis E. Young
Consulting Mining Engineer
President AIME

Even more than Brutus, Dr. Young is an honorable man. So are all engineers, all honorable men.

## We Are Threatened

One of our Communist members apparently does not share our expressed belief in the last issue that the North Atlantic Pact is desirable, for we have received an anonymous communication in big black print (no skull and crossbones however) that says: "North Atlantic Pact Means the Beganing of Wa #III and the End of America and You!" [sic] With only a slight tremble, we agree that our friend may be right, but the alternative, as we see it, is to let the Communists take over the world peaceably, and we prefer to take the chance of standing our ground with a gun.

## Gold in the Black Hills

Robert J. Casey has just published a book entitled "The Black Hills and Their Incredible Characters," and those interested in the folklore of one of our oldest mining districts will find much in it of interest. It includes, of course, the story of the biggest gold mine in the United States, the Homestake, and of other attempts to mine gold in the district. "It seems strange to me that there should be so little successful mining of precious metals in these parts today," the author reports himself as saying to Chambers Kellar, general counsel for the Homestake. "Surely there is as much gold in the ground as was ever taken out." "Well," said Mr. Kellar, "that is one theory. The other theory is that there isn't."

The matter was never so clearly stated in an AIME T.P.

# Among the Student Associates

This "rogues gallery" represents about half of the 100 members of the Mackay School of Mines' Crucible Club. President A. H. Barrios is seen at extreme left.

## Lafayette College

The John Markle Society's last technical meeting of the year was held on April 26. It was highlighted by a spectacular demonstration of velocity power tools, given by W. S. McConnell, of the Mine Safety Appliances Co. A slide film, "The Changing World," was also presented, with a commentary by William Shaffer, metallurgical engineer of the class of '49. Society members wound up the session with the usual refreshments.—*John Siergiej, Jr., Secretary.*

## Louisiana State University

The reactivated Student Chapter at LSU has been busy meeting bimonthly to hear interesting speakers, and arranging a student paper contest. Dan Grady, of the Hycalog Co., addressed the March 24 meeting, presenting a paper on "Hydrocarbon Profiles in Mud Logging." On April 7, J. E. Smith, of the Johnston Oil Field Service Corp., offered his paper entitled "Drill Stem Testing Procedure in Open Hole."

The Chapter is now engaged in a student paper competition, the winners of which will present their work before the Delta Section, AIME, sometime in April.—*Mahlon F. Manville, Corresponding Secretary.*

## Yale University

At its Dec. 2 meeting, the Yale Metallurgical Society was addressed by Richard J. Christine, metallurgist of the American Brass Co. at Torrington, Conn. Mr. Christine discussed the question of what industry expects of the newly graduated metallurgist. The personal relations of the engineer in industry were emphasized, and Mr. Christine told some of his interesting experiences. Following the formal address questions were asked and discussion ensued. The February 15 meeting was addressed by I. J. Hook, research Engineer of American Brass Co., Ansonia, Conn. The Society's President, Denis A. Nankivell, introduced Mr. Hook, who discussed the general aspects of Anaconda copper production in the Montana area before showing a movie on this subject. The movie covered the mining, smelting, and refining of copper in the district. Mr. Hook concluded his address, and the meeting, with a discussion period. About twenty-five members attended the meeting.—*Voluntine T. Potter, Secretary.*

### Current Institute Papers

*The following papers in the three journals are available to Institute members. Each member will receive one classification in the journal of his choice. Members may obtain papers in the two remaining classifications by purchasing the indicated issue of the journal at $0.75 per copy. There are no separate copies of the individual papers. ME means Mining Engineering, JM Journal of Metals, and JPT Journal of Petroleum Technology.*

### Metals Papers

Cadmium Recovery Practice in Lead Smelting. By P. C. Feddersen and H. E. Lee. February JM.

Development of Muffle Furnaces for the Production of Zinc Oxide and Zinc at East Chicago, Ind. G. E. Johnson. February JM.

The Effect of Orientation Difference on Grain Boundary Energies. By. C. G. Dunn and F. Lionetti. February JM.

Solubility Relationships of the Refractory Monocarbides. By J. T. Norton and A. L. Mowry. February JM.

Pressure Distribution in Compacting Metal Powders. By Pol Duwez and Leo Zwell. February JM.

Preferred Orientation in Rolled and Recrystallized Beryllium. By A. Smigelskas and C. S. Barrett. February JM.

Self-Diffusion in Sintering of Metallic Particles. By G. C. Kuczynski. February JM.

Homogeneous Yielding of Carburized and Nitrided Single Iron Crystals. By A. N. Holden and J. H. Hollomon. February JM.

The Surface Tension of Solid Copper. By H. Udin, A. J. Shaler, and John Wulff. February JM.

The Ionic Nature of Metallurgical Slags—Simple Oxide Systems. By John Chipman and Lo-Ching Chang. February JM.

Properties of Chromium Boride and Sintered Chromium Boride. By S. J. Sindeband. February JM.

Magnesium-Lithium Base Alloys—Preparation, Fabrication, and General Characteristics. By J. H. Jackson, P. D. Frost, A. C. Loonam, L. W. Eastwood, and C. H. Lorig. February JM.

The Recovery of Cadmium from Cadmium-copper Precipitate By G. H. Anderson. March JM.

Electrolytic Zinc at Risdon, Tasmania, Major Changes Since 1936. By S. W. Ross. March JM.

The Hardenability Effect of Molybdenum. By J. M. Hodge, J. L. Giove, and R. G. Storm. March JM

A Method of Examination of Fine Metal Powder Particles with the Electron Microscope. By Laurence Delisle. March JM.

The Effect of Ferrite Grain Size on Notch Toughness. By J. M. Hodge, R. D. Manning, and H. M. Reichhold. March JM.

Recrystallization and Microstructure of Aluminum Killed Deep Drawing Steel. By R. L. Rickett, S. H. Kalin, and J. T. MacKenzie, Jr. March JM

Precipitation Phenomena in the Solid Solutions of Nitrogen and Carbon in Alpha Iron Below the Eutectoid Temperature. By L. J. Dijkstra. March JM.

Concentration of the $SO_2$ Content of Dwight-Lloyd Sintering Machine Gas by Recirculation. By W. S. Reid. April JM.

The Crystal Structure of $Ni_4W$. By E. Epremian and D. Harker. April JM.

Sulphur Equilibria Between Iron Blast Furnace Slags and Metal. By G. G. Hatch and John Chipman. April JM.

The Beryllium-iron System. By R. J. Teitel and Morris Cohen. April JM.

Discussion, Institute of Metals Division. May JM.

The Effect of High Copper Content on the Operation of a Lead Blast Furnace, and Treatment of the Copper and Lead Produced. By A. A. Collins. May JM.

What is Metallurgy? By John Chipman. June JM.

The Sigma Phase in Ternary Cr-Co-Fe and Cr-Co-Ni Alloys. By P. A. Beck and W. D. Manly. June JM.

Distillation of Zinc From Copper Base Alloys and Galvanizers Drosses. By F. F. Poland. June JM.

Cadmium Recovery Practice at the Donora Zinc Works. By G. T. Smith and R. C. Moyer. June JM.

The Statistical Nature of the Endurance Limit. By J. T. Ransom and R. F. Mehl. June JM.

Investigation of Temper Brittleness in Low-alloy Steels. By S. A. Herres and A. R. Elsea. June JM.

Oriented Arrangements of Thin Aluminum Films on Ionic Substrates. By T. N. Rhodin, Jr. June JM.

P-type and N-type Silicon and the Formation of the Photovoltaic Barrier in Silicon Ingots. By J. H. Scaff, H. C. Theuerer, and E. E. Schumacher. June JM.

Microstructures of Silicon Ingots. By W. G. Pfann and J. H. Scaff. June JM.

## Mining Papers

Alluvial Tin Mining in Malaya. By A. D. Hughes. March ME.

Sampling of Coal for Float and Sink Tests. By A. L. Bailey and B. A. Landry. March ME.

Drilling Blastholes at the Holden Mine with Percussion Drills and Tungsten Carbide Bits. By E. A. Youngberg. March ME.

Aerial Photographic Contour Maps for Strip Mines. By George Hess and R. H. Swallow. April ME.

Drying of Low-rank Coals in the Entrained and Fluidized State. By V. F. Parry, J. B. Goodman, and E. O. Wagner April ME.

Coal Washing in Colorado and New Mexico. By J. D. Price and W. M. Bertholf. April ME.

The Rupp-Frantz Vibrating Filter. By W. M. Bertholf and J. D. Price. April ME.

Synthetic Liquid Fuels from Coal. By J. D. Doherty. April ME.

Drilling and Sampling Unconsolidated Materials. By L. W. Dupuy. May ME.

Effects of Rod Mill Speed at Tennessee Copper Co. By J. F. Myers and F. M. Lewis. May ME.

Temperature Compensation of Old Type Askania Magnetometers. By T. Koulomzine. May ME.

Municipal Water Needs vs. Coal Mine Stripping. By G. M. Dexter. May ME.

Correlation of the Performance Characteristics of Domestic Stoker Coals With Their Chemical and Petrographic Composition. By R. J. Helfinstine and G. H. Cady. May ME.

Ready-Made Heat From Coal. By D. W. Loucks. May ME.

Sinking With the Hydro-mucker at Mather "B" Shaft. By J. S. Westwater. June ME.

Diamond Drilling Quartz-feldspar Intergrowths. By L. C. Armstrong. June ME.

Safety Practices at the Crestmore Mine of the Riverside Cement Co. By R. H. Wightman and G. H. Adams. June ME.

Sintering Characteristics of Minus Sixty-five and Twenty Mesh Magnetite. By Alan Stanley and J. C. Mead. June ME.

Humphreys Spiral Concentration on Mesabi Rrange Ores. By W. E. Brown and L. J. Erck. June ME.

Formation and Properties of Single Crystals of Synthetic Rutile. By C. H. Moore, Jr. June ME.

Coal Washing in Washington, Oregon and Alaska. By M. R. Greer and H. F. Yancey. June ME.

A Study of Coal Classification and Its Application to the Coking Properties of Coal. By Michael Perch and C. C. Russell. June ME.

An Evaluation of the Performance of Thirty-three Residential Stoker Coals. By J. B. Purdy and H. W. Nelson. June ME.

Work of the U. S. Geological Survey on Coal and Coal Reserves. By Paul Averitt. June ME.

## Petroleum Papers

Semi-automatic Power-Operated Drilling Machinery. By M. E. True and B. L. Stone. February JPT.

The Core Recorder. By Clark Millison. February JPT.

Capillary Pressures—Their Measurement Using Mercury and the Calculation of Permeability Therefrom. By W. R. Purcell. February JPT.

Effects of Transient Conditions in Gas Reservoirs. By D. T. MacRoberts. February JPT.

Outline of Weather and Wave Forecasting Techniques. By A. H. Glenn and J. E. Graham. February JPT.

A Study of Oil and Gas Conservation in the Pickton Field. By J. R. Welsh, R. E. Simpson, J. W. Smith, and C. S. Yust. March JPT.

Methane Hydrate at High Pressure. By Riki Kobayashi and D. L. Katz. March JPT.

Method of Establishing a Stabilized Back-pressure Curve for Gas Wells Producing From Reservoirs of Extremely Low Permeability. By E. R. Haymaker, C. W. Binckley, and F. R. Burgess. March JPT.

Gas Hydrates of Carbon Dioxide-Methane Mixtures. By C. H. Unruh and D. L. Katz. March JPT.

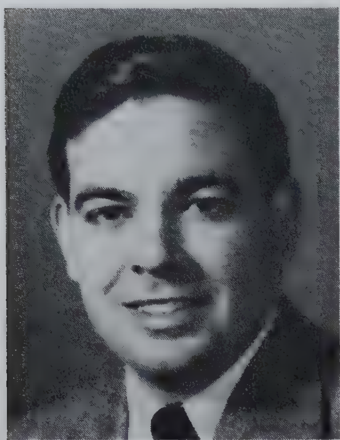
Gas Hydrates of Carbon Dioxide-Methane Mixtures. By C. H. Unruh and D. L. Katz. April JPT.

Gulf of Mexico Floating Drilling Tender. By C. P. Besse and G. W. Osborne. April JPT.

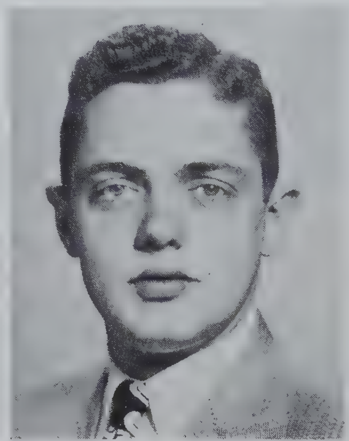
Estimation of Reserves and Water Drive From Pressure and Production History. By E. R. Brownscombe and Francis Collins. April JPT.

Relation Between Pressure and Recovery in Long Core Water Floods. By J. N. Breston and R. V. Hughes. April JPT.

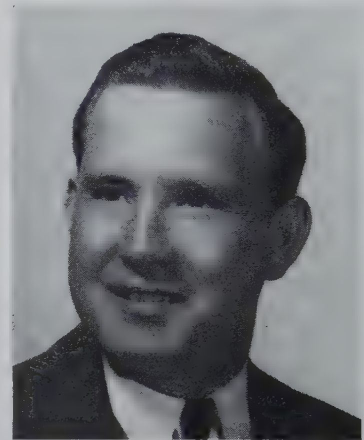
# News of AIME Members



Harry L. Kirkpatrick



Alvey B. Rushton



George R. Eadie

Two more outstanding coal mining students, **Harry L. Kirkpatrick** of the University of Kentucky, and **Alvey B. Rushton,** of Lehigh University, have been honored by the Old Timers Club for scholastic excellence and evidence of being "likely to succeed." In addition, the Club has chosen **George R. Eadie** for citation as the most outstanding mining graduate of the year.

Mr. Kirkpatrick, who will receive his B.S. degree in June, was awarded an engraved gold watch at a general engineering assembly on Feb. 10 by **E. R. Price,** chairman of the AIME Coal Division. The lucky recipient is from Lexington, Ky., married, and the grandson of Harry L. Kirkpatrick, long prominent in the Western Kentucky coal industry.

Mr. Rushton hails from New Kensington, Pa., and is following in his family's footsteps in entering the coal industry. He's a veteran of two years' wartime service with the Marines, and was elected to Tau Beta Pi at Lehigh, which school he entered in 1944. **J. Ray Ulrich** made the gold watch award on March 24.

Mr. Eadie graduated from the University of Illinois in February of this year, and is now employed by the H. C. Frick Coal Co., Pittsburgh. His three years in the Army Air Forces followed a stint at the University of Southern Illinois, and then postwar studies brought him to the Missouri School of Mines, which he attended until 1948. Last summer he worked in the engineering department of the Mt. Olive and Staunton Coal Co., before returning to the University to take his degree. **Paul Weir,** president of the Old Timers Club, and head of the Paul Weir Co., Chicago, made the award, an engraved gold pocket watch, at the March 8 meeting of the Mineral Industries Society.

**James Boyd,** Director of the U. S. Bureau of Mines, will be the principal speaker at the Montana School of Mines Commencement exercises on June 10.

**R. K. Comann** in November of last year was transferred from the U. S. Gypsum Company's Plaster City, Calif., plant to the home office in Chicago. Since that time he has been in the engineering department and now is working at the Staten Island, N. Y., plant.

**Walter B. Jones,** state geologist of Alabama, was elected president for 1949-1950 of the Association of American State Geologists at its annual meeting in San Francisco. He succeeds **Garland Peyton,** director of the Georgia Department of Mines, Mining, and Geology.

**Harry L. McKelvey** has left La Luz Mines Ltd., Siuna, Nicaragua, to accept the post of mine superintendent with the New Idria Honduras Mining Co. at Santa Rosa de Copan, Honduras.

**John A. Reeves,** former University of Utah student, is assistant mining engineer for the Independent Coal and Coke Co., Kenilworth, Utah.

**Jack W. Reinhart** is a junior geologist for the American Smelting and Refining Co., Silver City, N. Mex.

**A. E. Ring** retired from active service as manager of the Southwestern division of the Western mining department of the American Smelting and Refining Co. on March 1. He is at home at 2001 E. Elm St., Tucson, Ariz.

**K. A. Rogers** has moved to Phoenix, Ariz., from Chippewa Falls, Wis. He had been with the Bureau of Mines and is now engineer with the Davis Dam Transmission System, Parker Dam, Calif.

**James A. Ross** has been elected first vice-president of the Industrial Diamond Association of America.

**Morris E. Sandvig,** University of Minnesota man, is a testing engineer for the Erie Mining Co., Aurora, Minn. His mailing address is Box 147, Aurora.

**John T. Schimmel** is time study engineer for the Consolidation Coal Co., Rivesville, W. Va., and can be reached at 108 Chicago St., Fairmont, W. Va.

**Howard G. Schoenike** is a geologist with the M. A. Hanna Co. at Iron River, Mich. He was previously employed as a geologist for Butler Brothers, who recently sold their interest to M. A. Hanna.

**Dorner T. Schueler, Jr.,** has the job of engineer with the Industrial Minerals and Chemical Co., Berkeley, Calif., and is addressed in that city at 1155 Calusa Ave.

## U. S. Smelting Staff Changes at Midvale

**Robert Wallace** retired on April 1 as manager of the Midvale plant of the U. S. Smelting Refining and Mining Co. after 33 years of continuous service with the Company, beginning on Jan. 13, 1916, when he was employed as general roaster foreman. By 1924 he was superintendent of the Midvale plant and in 1939 he became its manager. He now winds up 44 years of interesting work and achievement in the mining and smelting industry. After graduating from Harvard in 1905 he went to work in the engineering department of the Cleveland-Cliffs Iron Co., departing from Ishpeming for Old Mexico where he was mining engineer for the AS&R at their properties in Santa Eulalia and Sierra Mojada. Back in the States in 1909, he worked for the Mammoth Copper Co., and the American Zinc, Lead and Smelting Co. In 1914 he went to Utah to work at the Utah Apex in Bingham as a metallurgist in the concentrator. Mr. Wallace recalls that while he was metallurgist of the mill during 1914 and 1915 flotation machines were installed to extract lead minerals from the ore and this, he believes, was the first application of flotation to concentrate lead ores that was made in the State of Utah.

**Hugo L. Johnson** became general superintendent of the Midvale plant of the U. S. Smelting Refining and Mining Co. on April 1 and has direct charge of all operations of the plant and of the ore purchasing department formerly handled by Mr. Wallace. Mr. Johnson started with the Company 33 years ago as a draftsman in a subsidiary, the U. S. S. Lead Refinery. In 1918 he was made supervisor of the employe service department and four years later became superintendent of the silver refinery. In 1931 supervision of the engineering and maintenance department was added to his duties. He then transferred to Utah as superintendent of the gold and silver parting plant at Midvale which was built in 1933 along with the Parkes process lead refinery. Continuing his upward motion, he was in charge of the construction and operation of a pilot zinc plant, night superintendent at Midvale, assistant smelter superintendent, and in 1946 was made assistant to the manager of the plan, which position he held until his recent promotion.

**Archie A. Nelson,** who has been research engineer and who will continue to direct that work, has been appointed assistant smelter superintendent. He succeeds **W. M. Whitecotton,** who has been assistant smelter superintendent and in charge of blast furnace operations, and who requested that he be relieved of the responsibility of these posts because of his health. Mr. Whitecotton will remain at the plant as research engineer. Mr. Nelson has been with the Midvale plant for the past twenty years except for six years as mill superintendent and assistant manager of a company subsidiary, MicMac Mines Ltd. in Canada. Mr. Whitecotton was foreman of the cadmium plant of Midvale in 1915 and 1916, after which he was with the Electrolytic Zinc Co. of Australasia as superintendent of its zinc plant at Hobart, Tasmania, until 1922 when he returned to this country. After eleven years in various places, he returned to Midvale as roaster superintendent.

**M. J. Belich** has become general roaster foreman at Midvale. He has worked there since he finished his studies at the University of Utah on the 1939 W. H. Eardley scholarship in metallurgy awarded by the Company. Since 1946 he has been night superintendent.

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**John F. Schultze** is a metallurgist in the Leadville milling unit of the American Smelting and Refining Co., Leadville, Colo. He receives his mail there at Box 27.

**R. R. Schultz** has resigned from his post with the Nordberg Mfg. Co. to become sales manager of the Willamette Iron and Steel Co., Portland, Oreg.

**John E. Schumacher, Jr.,** although addressed at P. O. Box 689, Pottsville, Pa., is a field geologist for the Stanolind Oil and Gas Co., Casper, Wyo.

**Henry E. Schweinsberg,** former vice-president and sales manager of the Fields Mfg. Co., is president of CAR-BIT, Inc., Highland Bldg., Pittsburgh 6, Pa.

**George C. Selfridge** has been appointed mine superintendent of the Fresnillo and Zacatecas mines of the Fresnillo Co., Fresnillo, Zac., Mexico. He was formerly associated with the Manhattan District and the Atomic Energy Commission as chief of the exploration branch, raw materials division.

**Paul Semko** is chief of party of the geophysical exploration division of the Pennsylvania Turnpike Commission, doing geophysical field operations and earth resistivity determinations. His address is 646 Warren Ave., Kingston, Pa.

**Arthur E. Shannon** is sales engineer for the Jeffrey Mfg. Co., with a mailing address at P. O. Drawer 1078, Morgantown, W. Va.

Charles Gottschalk

**Charles Gottschalk** spent a month this spring in the States visiting his son and family in Baltimore after completing a two-year assignment in Japan as consultant on coal production problems. He is attached to the economic section of Military Government and expected to report back for duty early in May.

**Ely Silverman,** of the Tennessee Copper Co., is in Oak Ridge, Tenn., studying the techniques of using radioisotopes in research. He is one of 32 scientists from the States and several foreign countries enrolled in the seventh in a series of one-month courses offered by the Oak Ridge Institute of Nuclear Studies.

**Raymond L. R. Slacke** is employed by the National Coal Board, West Midlands division, in the capacity of area coal preparation engineer, Shropshire and South Staffordshire area, England.

**R. Cecil Smart** presented his paper on the Restoration of Productive Efficiency in Britain's Coal Industry before the Economic Reform Club and also before the Association of Colliery Managers, on Feb. 10. The paper's value was attested by the fact that a number of members of the National Coal Board attended his lecture, including representatives from the London office of the Board. His papers will be published in the proceedings of the National Association of Colliery Managers and quoted in the Iron and Coal Trade Review.

**C. T. Smith,** after 32 years as secretary and treasurer of the Missouri Co-

Mr. Mudd receiving citation for Egleston Medal from C. P. Davis, president of Columbia's Engineering School Alumni Association.

**Harvey S. Mudd** spoke on the importance of physical metallurgy in counteracting the depletion of our mineral resources at a meeting of the Columbia University Engineering School Alumni Association at which he was awarded the Egleston Medal for distinguished engineering achievement. He said in part:

"The second World War has given rise to much debate about the exhaustion of our mineral resources and in the name of conservation many measures have been proposed. That exhaustion is taking place cannot be denied. It is the rate of exhaustion that now gives concern, and properly so, but it should not be viewed with too great alarm.

"I cannot convince myself that the advance of civilization will be retarded by a deficiency of mineral resources, providing one condition is met, which condition is that research in the fundamental and applied sciences and engineering is wisely and generously supported. Our physical metallurgists are offering new alloys and new processes that give materials having superior properties to engineers with which to work and it is incumbent upon the engineers to make the best use of them, always with the future in mind."

In discussing his talk Mr. Mudd expressed concern over the relatively few students being graduated in metallurgical engineering as compared to other fields of engineering, and the need for metallurgical engineers in research and industry. He noted that research work required a particular type of individual with postgraduate training. Research work being done now in universities not only produced needed information but either directly, or through the faculty, helped to teach research techniques and helped universities to hold some exceptionally talented faculty that they could not otherwise hold.

He commented on the rapid industrial recovery being made in many of the western European countries. He was opposed to both direct subsidies and high tariffs, and pointed out that under normal conditions both were extravagant and interfered with free enterprise.

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balt Co. of Fredericktown, Mo., has resigned that post and now has retired from active business. Previous to joining Missouri Cobalt, he was accountant for El Oro Mining and Railway Co. at El Oro, Mexico. Mr. Smith can be reached at 118 E. Coolidge St., Harlingen, Texas.

**Richard A. Smith** retired as state geologist on the Michigan Geological Survey in 1946. Now he is special lecturer in geology at Michigan State College and is doing consulting work.

**Robert E. Sorenson** has been made chief engineer of the Hecla Mining Co. at Wallace, Idaho.

**H. A. Steane** has been appointed to the post of mill superintendent of Uruwira Minerals Ltd., Mpanda, via Uvinza, Tanganyika.

**J. B. Stapler** recently received appointment as managing director of Marsman Hongkong China, Ltd., P. O. Box 500, Hongkong & Shanghai Bank Bldg., Hongkong. Mr. Stapler has been with the Marsman interests for sixteen years and prior to the war was one of the senior engineers of Marsman & Co. The rapid development of mines such as Itogon, San Mauricio, and United Paracale, was largely due to his capable direction. Since his return from internment he has been a director of Marsman Investments, Ltd., and connected with the Marsman Co. of California directing from San Francisco the operations on Okinawa. Mr. and Mrs. Stapler departed on the President Cleveland March 9 for Hongkong where Mr. Stapler will take over his new duties.

**Forest J. Sur,** mining engineer and geologist formerly with the Bureau of Mines and now with Joe T. Juhan, recently completed a six-month examination and report on an oil shale project near Meeker, Colo., for Juhan and Associates. This done, he went to Farmington, N. Mex., to complete a reconnaissance of San Juan County, with the object of choosing sites for drilling deep wells to Pennsylvanian formations. He spent seven months on this work last year.

**William H. Swayne,** formerly in the geological department of the Anaconda Copper Mining Co., has gone to Santiago, Chile, as exploration geologist for Cia. Sud Americana Exploradora de Minas.

**Ray E. Tower** has resigned as general superintendent of the Mica Mountain Mines, South Pass City, Wyo. His new address is 621 S. W. Temple St., Salt Lake City, He is currently interested in mine development in the Masonic area, Mono County, Calif., and in the Tintic area in Utah.

**Max A. Tuttle** for the past 22 years has been employed by the Knox Consolidated Coal Corp. On Dec. 16, 1948, he became associated with the Enos Coal Mining Co., 1405 Merchants Bank Bldg., Indianapolis 4, Ind.

**Gailen T. Vandel** has accepted a post with the Cerro de Pasco Copper Corp. in Peru and expected to leave the States early in March.

**Roy Van Zante,** who was addressed at the Bureau of Mines in Rolla, Mo., can now be reached at the U. S. Vanadium Corp., Rifle, Colo.

**L. A. Walker** returned to Salt Lake City in March from a two-month professional trip to Colombia. Traveling to his destination in the Andes near the border of Ecuador his modes of transportation scaled from plane to auto and finally to mule. He stopped over long enough to meet members in Medellin, Cali, and Pasto.

**S. Power Warren** wishes to advise his friends that he has returned to Washington, D. C., after spending most of the first three months of the year studying the various mines and phosphate matrix treating plants of the

Florida field. During his stay he attended the meetings of the local phosphate group of the AIME and reports that the meetings were well attended by representatives of all the operating companies and the programs were enjoyable. His advice to the members contemplating a trip into this field is that they arrange their schedule to be there the first Monday of the month because at no other time will so many members be available in one place.

**Donald R. Wells,** of 153 Fallis Rd., Columbus 2, Ohio, is employed at Battelle Memorial Institute as a laboratory technician in the electron microscopy division.

**Richard H. Wesley,** with his two partners, after several years' study of the field, have gone into the consulting geological engineering business as Wesley, Bedford and Stickel, 2370 Penobscot Bldg., Detroit 26, Mich. Mr. Wesley writes: "We are in a position to carry on any type of exploration work any place in the world. This includes airborne geophysical work. Our laboratories are equipped for analyses of mining, petroleum products, and complete studies in soil mechanics. We can carry on spectrographic, petrographic, and core testing analyses. Our activities are not only confined to mining and petroleum, but also embrace preliminary studies for any major civil engineering project."

**Joseph L. Walker, Jr.,** holds down the job of research mining engineer with the Rimersburg Coal Co., Rimersburg, Pa.

**Robert Weagel,** formerly shift foreman of the U. S. Section of the U. S. Smelting Refining and Mining Co., was appointed assistant general mine foreman of the section on Feb. 1.

**J. P. Weir** received the degree of bachelor of science in mining engineering at the midwinter commencement exercises of the Pennsylvania State College. At the same exercises, the technical degree, engineer of mines, was conferred upon his father, **Paul Weir.** Mr. Weir is now associated with his father in his consulting mining engineering firm, the Paul Weir Co.

**Henry P. Whaley** has the job of testing engineer with the Erie Mining Co., Hibbing, Minn.

**A. D. Wilks** was appointed superintendent of the Ordnance Factory, Katni (C.P.) India, over a year ago.

**James W. Wivell** has joined the staff at the Embarrass iron mine of Pickands Mather & Co.

**Edward H. Snyder,** president of the Combined Metals Reduction Co., Salt Lake City, was elected president of the American Zinc Institute at the annual meeting of the board of directors, succeeding **Howard I. Young,** who has held the office since 1935. New vice-presidents include **George Mixter,** vice-president of the U. S. Smelting Refining and Mining Co., Boston, and **Raymond F. Orr,** president and general manager of the Athletic Mining and Smelting Co., Ft. Smith, Ark. **Erle V. Daveler,** vice-president of the American Zinc, Lead and Smelting Co., New York City, was elected treasurer and **Ernest V. Gent** was reelected executive vice-president and secretary. To serve as directors until 1952 are **A. E. Bendelari, O. W. Bilharz, C. M. Chapin, Jr.,** and **S. H. Levison.**

H. I. Young shows his successor as president, E. H. Snyder, a clock given him by the institute in token of his long service.

**L. E. Young** visited the McLeod River property of Canadian Collieries (Dunsmuir) Ltd., Nanaimo, B. C., the first week in April, thence proceeding to the Vancouver Island headquarters of the Company for an inspection of properties and consultation with **H. R. Plommer,** managing director.

## • In the Metals Divisions

**Paul H. Anderson** received his M.S. degree on March 17 from the University of Minnesota, where he majored in metallography, and minored in industrial engineering. The title of his thesis is "Hot Dip Tinning of Low Carbon Steels." He intends to remain at the university to work toward a Ph.D. degree.

**Bernhard Blumenthal,** formerly research metallurgist with the American Platinum Works, Newark, N. J., has joined the staff of the Argonne National Laboratory, Chicago, Ill., as an associate metallurgist.

**Chester L. Brown** can now be reached at the production division of the development and research department of the Continental Oil Co., Ponca City, Okla.

**D. S. Cameron** has been made open hearth superintendent of the Wickwire Spencer Steel Division of the Colorado Fuel and Iron Corp. Buffalo plant.

**Harry A. Campbell,** executive engineer for Fredric Flader, Inc., manufacturer of gas turbines, receives mail at 341 Goundry St., Apt. 4, N. Tonawanda, N. Y.

**Gregory J. Comstock,** director of research of the powder metallurgy laboratory at Stevens Institute of Technology, left on April 5 by military transport for a month's stay in England, Germany, and Austria, on a commission for the Bureau of Ships of the U. S. Navy Department. The purpose of the visit was to discuss parallel research projects with British Governmental agencies. He visited the Edelstahlwerke and Verienegeste-Stahlwerke plants in Germany to study the current industrial application of chromizing. During the recent war, Professor Comstock served in Germany for the U. S. Joint Chiefs of Staff. Returning to this country, he was connected with the FEA and later with the U. S. Department of Commerce. Professor Comstock, on the Stevens staff since 1939, occupies the first chair of powder metallurgy established in any institution of learning in the States.

**Minu N. Dastur** has the job of metallurgical staff assistant with H. A. Brassert & Co., New York City.

**Robert B. Day,** now with the Linde Air Products Co., New York City, is in the Company's cylinder inspection and maintenance department as inspector for purchasing of pressure vessels.

**Gerhard Derge** and **Frederick N. Rhines** have been appointed to full professorships in the department of metallurgical engineering, college of engineering and science at Carnegie Institute of Technology effective Sept. 1. Both men joined the Carnegie staff in 1934. Dr. Derge, who graduated from Amherst and received his Ph.D. from Princeton, is a member of the Electric Furnace Steel Conference Committee of the Iron and Steel Division, AIME. Dr. Rhines, a Michigan and Yale graduate, is the Aluminum Co. of America professor of light metals and a two-time winner of the Institute of Metals award.

**Denton T. Doll** joined the staff of the chemistry and metallurgy division of the University of California Los Alamos Scientific Laboratory on April 11. He had been with the Brush Beryllium Co. in Cleveland.

**Kenneth L. Erickson** is employed as a chemist in process research by the Basic Reduction Co., Henderson, Nev.

Clyde R. Tipton, Jr.

**Clyde R. Tipton, Jr.,** joined the staff of the chemistry and metallurgy division of the Los Alamos Scientific Laboratory, P. O. Box 1663, Los Alamos, N. Mex. He had been with Battelle Memorial Institute.

**R. R. Estill** has been made general superintendent of the fluorspar division of the U. S. Coal and Coke Co. at Mexico, Ky., replacing **K. A. Johnston,** who was transferred to the construction division at Lynch, Ky., on March 15.

**J. Leon Gittlen** is president and production manager of the Consumers Metal Corp., smelters and refiners of metals, Detroit.

**Lawrence G. Glasglow,** although still employed in the materials laboratories of Chance Vought Aircraft, is reached now at 1113 Canterbury Ct., Dallas, Texas, since the company has moved from Stratford to Dallas.

**Richard A. Gorski** is foreman relief trainee in the blast furnace division of the Gary works of the Carnegie-Illinois Steel Corp. His address is 4447 Grant St., Gary, Ind.

**Charles H. Homer, Jr.,** formerly plant superintendent of the Beaumont Iron Works Co. at Beaumont, Texas, has been transferred to the Dunkirk, N. Y., plant of the parent organization, American Locomotive Co., Alco products division, where he assumes the duties of chief quality control engineer. The Dunkirk plant produces heat exchangers, pressure vessels, prefabricated pipe, large diameter pipe and other equipment for the petroleum, chemical, and allied industries. Mr. Homer's new mailing address is 353 Temple St., Fredonia, N. Y.

**Carl H. Himmelman** is a supervisory trainee with the Timken Roller Bearing Co. at Canton, Ohio.

**Harry K. Ihrig,** vice-president and director of laboratories of the Globe Steel Tubes Co., Milwaukee, Wis., received a citation for distinguished service in engineering from the College of Engineering of the University of Wisconsin at Madison on March 15.

**Paul Linz** resigned as a partner of Carl M. Loeb, Rhoades & Co. effective April 30, to become personal assistant to Dr. Mauricio Hochschild in all enterprises with which he is connected.

**Roger D. Moeller** joined the staff of the chemistry and metallugy division of the University of California Los Alamos Scientific Laboratory on March 21. He had been with the Sharples Corp. research laboratory in Philadelphia.

**Claude R. Monlux** graduated from Yale in February and is now employed in a training capacity by the Ohio Steel Foundry Co. of Springfield, Ohio.

Norman F. Tisdale

**Norman F. Tisdale,** chief metallurgical engineer of the Molybdenum Corp. of America since 1933, has been made manager of sales. A native Canadian and graduate of Queen's University, Kingston, Ont., he is well known in the iron and steel industry.

**David P. Moore,** of 68 Muskoka Rd., Grosse Pointe Farms 30, Mich., is metallurgist for the Hudson Motor Car Co., Detroit, Mich.

**Thomas C. Nelson, Jr.,** is metallurgist for the General Electric Co. at the Hanford works in Richland, Wash.

**William H. Nikola,** who lives at 83 Highland Ave., Jersey City, N. J., is quality control engineer for the Westinghouse Electric Corp.

**Leon V. Omelka** is working as testing engineer for the Permanente Metals Corp., Trentwood, Wash. His mail goes to S. 4114 Ivory, Spokane, Wash.

**Joseph R. Patterson, Jr.,** is at 468 Market St., Beaver, Pa., working for the Babcock and Wilcox Tube Co.

**Burton C. Person,** of 315 St. Louis St., Baton Rouge, La., is metallurgist in the Louisiana division of the Esso Standard Oil Co.

**Fred P. Peters,** editor-in-chief of *Materials & Methods,* has been made vice-president and publishing director of the book division of the Reinhold Publishing Corp., New York City 18.

**Chester F. Robards** is research metallurgical engineer on aircraft engines at the NACA Lewis Flight Propulsion Laboratory, Cleveland. He lives at 14029 Gramatan Ave., Cleveland 11, Ohio.

**Leonard W. Rothe** is a metallurgical trainee with the Armco Steel Corp., Middletown, Ohio. His home address is 2205 Lamberton St., Middletown.

**Philip S. Savage, Jr.,** is working for the McCallum Bronze Co., Buffalo, N. Y. His address there is 242 4th St.

**Arthur B. Shuck,** formerly a research metallurgist with the metal products division of the Koppers Co., is now in the metallurgical section of the Argonne National Laboratory.

**John A. Swift** has formed the Swift Industrial Chemical Co., Hartford 1, Conn., to manufacture a complete line of chemical and metallurgical materials for metal cleaning, blackening, and heat treating. Mr. Swift has had extensive experience in the metal manufacturing, fabricating, and processing industries, having done work for the Western Electric Co., the American Steel and Wire Co., the Billings and Spencer Co., and the Heatbath Corp. In addition to his industrial experience, he has organized and instructed various metallurgical courses for evening divisions of the Hillyer College, New Haven Junior College, and the University of Connecticut. A registered metallurgical engineer in Connecticut, he is also engaged in consulting on heat treating, testing, surface finishing and treating, and fabricating of metals and metal products. Recently he served on the New England AIME Committee for the 1949 Regional Conference held in Springfield, Mass.

**J. D. Swindale** has left the Mond Nickel Co. and has resumed his war-interrupted studies at Birmingham University, Edglaston, Birmingham 15, England.

**E. T. Turkdogan** was recently awarded the degree of Master of Metallurgy in recognition of his research work on slag metal reactions at the University of Sheffield, Sheffield, England.

**Joe G. Uzelac,** formerly a student at the University of Utah, is working for the Denver Equipment Co., Denver, Colo., as a metallurgical engineer.

**Ralph L. Wilcox,** metallurgical engineer and vice-president of the Gerity-Michigan Corp., is now serving on loan from his company as chief of the nonferrous metals branch of the ECA in Washington, D. C. Mr. Wilcox says he would welcome a visit from any of his old WPB friends.

**Tzuliang Wu** is research engineer at the Institute of Industrial Research, Syracuse University, Syracuse, N. Y.

## • In Petroleum Circles

**Bernard W. Allen,** former Colorado School of Mines student, has become a petroleum engineer with the Ohio Oil Co., Box 530, Cody, Wyo.

**Joseph A. Buland, Jr.,** is currently employed by the Baroid Sales Division of the National Lead Co. as drilling mud service engineer in southwestern Wyoming. His mailing address is in care of the Teton Hotel, Riverton, Wyo.

**John H. Dante** is geologist and production manager with F. G. Fox and W. J. Fox of Owensboro, Ky. His address there is 829 Griffith Ave.

**Harry Dereniuk,** formerly with the Republic National Gas Co., is now with the Conroe Drilling Co., Corpus Christi, Texas, as a petroleum engineer.

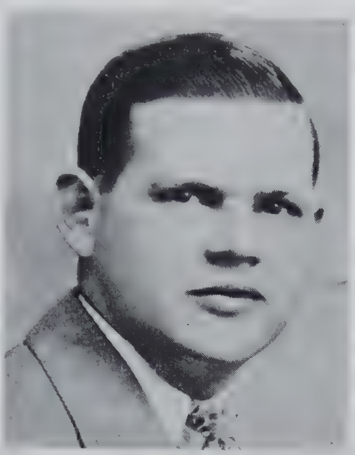
**Hal B. Fullerton, Jr.,** is an engineer in training with The Texas Co. at Long Beach, Calif. He lives at 336 Prospect Ave., Long Beach.

**James R. Graham,** after graduating from Louisiana State in January, accepted a job as petroleum engineer with the Standard Oil Co. of Texas. At present he is located in the Western division office in Midland, Texas.

**Edward A. Gribi, Jr.,** finished his studies at Stanford last December and has been employed as a geologist by the Sinclair Petroleum Co. for exploration work in Ethiopia.

**John J. Jakosky, Jr.,** is engineer with International Geophysics Inc., 1063 Gayley Ave., Los Angeles 24.

**Robert Kamon,** former University of Texas student, is a junior partner in the firm, Kamon Petroleum Exploration, Cisco, Texas.



W. D. Beach

**W. D. Beach,** petroleum engineer with the Gulf Oil Corp., recently joined the reservoir section of the executive department in Houston, Texas. He was formerly with the Gulf production division of the Gulf Refining Co. at Laurel, Miss. Mr. Beach is a Penn State graduate and served as secretary-treasurer of the Mississippi Subsection of the Delta Section, AIME, for the last half of 1948.

Julie Anne Klovstad

**Julie Anne Klovstad,** formerly geologist with the Shell Oil Co. at Jackson, Miss., is now doing consulting work in eastern Colorado as well as working toward a Ph.D. degree at the University of Colorado. She may be reached at 1135 University Ave., Boulder.

**Philip Kraft** resigned as a director of the Magma Copper Co. last December 15.

**Frank E. Long** graduated from the University of Oklahoma with a degree in petroleum engineering and at present is employed by the Magnolia Petroleum Co. as an engineer trainee. His address is General Delivery, Falfurrias, Texas.

**Charles T. McClure,** formerly with the Signal Oil and Gas Co., has become associated with the Youngstown Sheet and Tube Co., Los Angeles, as a field engineer.

**R. B. Luke McCullar,** who is sales engineer for the Western Co., can be reached at Box 310, Midland, Texas.

**Kenneth E. Meyer,** petroleum engineer with the Cities Service Co., New York City, has been transferred to the Gulf Coast division. His new address is 1440 Mellie Esperson Bldg., Houston 2, Texas.

**James I. Morris** is working for the Pure Oil Co. as district production engineer. Mail reaches him at Box 700, Worland, Wyo.

**Harold L. Patterson** is in Delmita, Texas, working for the Sun Oil Co. as a petroleum engineer.

**Warren D. Phelps,** who had been at Texas A&M, is working for the Magnolia Petroleum Co., Box 792, Drumright, Okla.

**Edward W. Racek,** former University of Tulsa student, has the job of petroleum engineer for the Acme Well Supply Co., New York City. His home is at 36 Dogwood Lane, Levittown, Hicksville, N. Y.

**Leslie B. Riggins, Jr.,** is chief engineer and geologist for the Portable Drilling Corp. His mail goes in care of the Company to P. O. Box 1318, Seminole, Okla.

**John L. Ross** is student engineer in the Gypsy division of the Gulf Oil Corp., Tulsa, but gets his mail at 112 N. Maiden St., Waynesburg, Pa.

**E. S. Rugg** can be reached in care of The Texas Co., New Castle, Wyo., where he is an engineer trainee.

**Irl Sandidge, Jr.,** formerly with the Ohio Fuel Gas Co., Columbus, is now addressed at the United Fuel Gas Co., Box 1273, Charleston 25, W. Va.

**W. S. Skinner** received an M.S. degree in geology from Lehigh last June and during the summer worked for the New York State Science Survey to finish an investigation of oil possibilities in Otsego County, N. Y., which was begun in the summer of 1947. Last October he took the job of geologist with the South Penn Oil Co., Parkersburg, W. Va.

N. A. Tinker, Jr.

**N. A. Tinker, Jr.,** joined the consulting engineering and geological firm of DeGolyer, MacNaughton & Murrell, Dallas, on March 15. While in Tulsa, before taking this latest post, he was sales contact engineer for the Weatherford Oil Tool Co., and prior to that was with the Gulf Oil Corp. as North Texas zone engineer.

**Carle F. Sharp, Jr.,** formerly a student at the University of Texas, is working as a junior reservoir engineer for the Humble Oil and Refining Co. His mail goes to Box 357, Katy, Texas.

**Duncan M. Smith, Jr.,** is now associated with the California Co. at the Lake St. John field at Waterproof, La.

**Henry J. Stewart,** now with the Union Oil Co. of California, P. O. Box 1365, Orcutt, Calif., used to be with the Sunray Oil Corp. in Alice, Texas.

**Reid T. Stone** is assistant field engineer for the Axelson Mfg. Co., Huntington Park, Calif. He lives in Apt. B, 8655 California Ave., Southgate, Calif.

**H. J. Struth,** former editor of the Petroleum Data Book, can now be reached in New York City at the American Petroleum Institute, Dept. of Information, 50 W. 50th St.

**Ralph E. Taylor,** who was with the Freeport Sulphur Co., joined the staff of Humble Oil and Refining Co. on March 15. He is addressed in care of the Company, Box 2180, Houston 1, Texas.

**J. U. Teague** resigned as superintendent of the Hogg Oil Co. on Feb. 1 to assume the presidency of the Columbia Drilling Co. This concern is engaged in the contract drilling of oil wells and maintains an office at 2011 Niels Esperson Bldg., Houston, with a field office and storage yard at West Columbia, Texas. Mr. Teague entered the oil business upon graduation from Rice Institute nineteen years ago as a petroleum engineer with the Humble Oil and Refining Co. He resigned in 1940 to become general superintendent of the Hogg Oil Co., interrupting this job with three years as a Lieutenant Commander in the Navy; he came out of service with seven battle stars in the Pacific theater. The Teagues live at 2406 Dorrington, Houston.

**John F. Truchot, Jr.,** is working for the Rocky Mountain division of the Stanolind Oil and Gas Co. as a geologist. His address is P. O. Box 40, Casper, Wyo.

**J. H. Van Zant** is vice-president of the Van-Grisso Oil Co., 1414 Fort Worth National Bank Bldg., Fort Worth 2, Texas.

**W. Frank West** is a petroleum-engineer trainee with the Continental Oil Co., P. O. Box 451, Ventura, Calif.

## Obituaries

### Sydney Hobart Ball

An Appreciation by Donald M. Liddell

Sydney H. Ball, a member of the Institute for 42 years, and Director from 1924 to 1927, died of a heart attack on Friday, March 25, at his home in New York City, aged 71 years and three months. He was active until the last, having been on professional work in British Columbia in December, when he had the first attack of his fatal illness.

Born in Chicago, he received in 1901 an A.B. degree from the University of Wisconsin, which awarded him a Ph.D. in 1910. He was one of the few who came into prominence in his youth. Having worked for the U. S. Geological Survey from 1903 to 1907, he was asked in the latter year to head an expedition to examine the concession of the Société International Forestiere et Miniere du Congo for the Ryan-Guggenheim group. Three years of work firmly established his reputation as an able field geologist and executive. It is probable that the Congo-Angola diamond field, an outgrowth of this expedition, is the richest known. From that time on, his services were in demand in every part of the world. From 1917 until his death he was associated with the firm of Rogers, Mayer and Ball, of which he was the last survivor.

He was three times decorated by the Belgian Government, first as Chevalier de l'Ordre Royal du Lion; second as Officier de l'Ordre Royal du Lion; and finally in January of last year, Commandeur de l'Ordre de Leopold II, the highest Belgian decoration that can be given a civilian.

For many years he had contributed the annual articles on gemstones to the Bureau of Mines Minerals Year Book, and had written for various trade publications. He was a member of the New York Jewelers' Publicity Committee and was largely responsible for the House of Jewelers at the New York World's Fair. A study that the writer found hugely entertaining embodied a long research into the use of gemstones by the Pre-Columbian Indians of the Americas.

In pure geology he made his mark by a study of Tertiary dikes and Pleistocene glacial deposits, which established the existence of two distinct ages in the so-called Front Range. He carried out the first accurate mapping of Death Valley, Calif., about 1907.

Known to the engineers and geologists of the world by reputation, his personality endeared him to his associates here. He was a charter member and later president of the Mining Club of New York City. He had been a member of the Mining and Metallurgical Society of America for 37 years and was its president in 1933. He was president in 1930 of the Society of Economic Geologists, and an honorary member of the Gemological Institute of America and of the Chemical, Mining and Metallurgical Society of South Africa. He was a member and one-time governor of the Explorers Club, and a director of the CRB educational fund.

One can give only a bare outline of his long and busy life. One cannot put on paper a proper appreciation of his serious conversation or of his impish delight in jokes on those he knew well. Nor can one express an adequate acknowledgment of his readiness to put his knowledge at the service of his friends.

ELWOOD BACHMAN (Member 1940), who was recently engaged in the electrification of the Utah Copper Company's Bingham property, and who had been associated with the General Electric Co. since 1916, died last Dec. 16. A man of many talents and interests, Mr. Bachman, when he received his E.E. degree from the University of Utah in 1916, already had three years of mine electrification, railway construction, and test work behind him. After joining General Electric he worked on mine in-

stallations, mill electrification, and electrolytic investigation projects, was at the same time in complete charge of electrical engineering at the Flin Flon plant of the Hudson Bay Mining and Smelting Co. in Hudson Bay.

LeGRANDE D. BARRETT (Member 1939), mining engineer, is dead. Mr. Barrett died at the age of 33 in South Africa, while acting as a Mormon missionary there. He had resigned, in 1946, his job as acting branch manager for the Salt Lake City office of the Independent Pneumatic Tool Co., in order to go on the mission. After receiving his B.S. in mining engineering from the University of Utah in 1941, Mr. Barrett worked for the Kennecott Copper Co., and then as an engineer for the New Park Mining Co., at Keetley, Utah, before taking his last professional job in 1944.

ARTHUR J. BOASE (Member 1936), former college professor and most recently manager of the Portland Cement Association's structural and technical bureau in Chicago, died recently. Before entering the University of Colorado in 1915, Mr. Boase had been superintendent of construction for the Boston Colorado Power Co. in Denver, and then assistant city engineer at Boulder. From 1920 to 1921 he studied at the University of Pennsylvania, and during those years and for three years thereafter was an instructor in civil engineering at that school. He then headed the department of civil engineering at Pennsylvania Military College for six years before joining the Portland Cement Association.

CHARLES EDWARD BRUFF (Member 1920), died in Berkeley, Calif., on Feb. 25 at the age of 72. He had been San Francisco representative for the Stevens Adamson Co. until his retirement several years ago.

It was 1895 when Mr. Bruff graduated from Purdue University with his degree in engineering, and for the ensuing fifteen years he was a draftsman for the L. C. Trent Co., assistant manager for the Bradley Engineering and Machinery Co., and a representative of the Power and Mining Machinery Co. in New York. Then he went on in 1910 to build the Chino mill in Hurley, N. Mex., and journeyed to Alaska to supervise construction of the Gastneau mill in Juneau, both assignments under the aegis of the D. C. Jackling engineering firm. After 1915 he was a partner in the Bradley, Bruff and Labarthe organization, actively engaged in the construction of the Alaska Juneau mill and the building of many domestic and foreign metallurgical plants.

EDWARD E. BUGBEE (Member 1905), nationally known for his work in mining and metallurgical engineering, and a professor emeritus at MIT, died suddenly in Boston, Mass., on Feb. 2, at the age of 72. Professor Bugbee graduated from MIT in 1900 and began his career as an instructor in that school's metallurgical laboratory the same year. In 1903 he was made an assistant professor at Iowa State College, but later returned to MIT, retiring as an associate professor of mining engineering and metallurgy in 1941.

LUCIUS A. BUTLER (Member 1920), died, at the age of 60, on Jan. 23. His last professional association had been with the U. S. Engineering Department in San Francisco. Mr. Butler was a graduate of the Michigan College of Mines, and spent the early years of his career with mining companies in Canada, Minnesota, and Michigan. He worked with the Inland Steel Co. for three years, and then became a project engineer with the Michigan State Highway department. In 1938 he joined the engineering corps of the War Department, working in his native Michigan until he moved to San Francisco.

FOREST L. CAMPBELL (Member 1940), chief engineer for the exploitation department, southern division, of Richfield Oil Co., died on Jan. 11 in Long Beach, Calif., of a heart attack. The 51 year old engineer's career began in 1918 with the San Dimas Co., in Mexico. He received an A.B. degree from the University of California in 1921, spent five years with the oil and gas division and State Mining Bureau of California, and joined the Richfield Co. in 1928, as a resident engineer. Mr. Campbell's chief interest was in petroleum, although mining geology and mining and milling also fell within the scope of his many abilities.

MARK G. CARHART (Member 1943), died on March 6 at the age of 66. Thus was ended an amazingly versatile career which created a man with broad managerial and engineering talents. At the turn of the century, Mr. Carhart was a young farm worker. A year later he was managing a lighting and water plant in Bartow, Fla.—and so it went through the first two decades—a continued eclectic interest in public power and private industry, from sales, production, and engineering viewpoints. The year 1930 found him managing the Venezuela Power Co. at Maracaibo. He was no stranger to Latin America, having served for the previous three years as chief engineer for the Westinghouse Corp. in Mexico City.

From 1931 to 1941 he represented Canadian mining operators in New York, developing finances and supervising hard rock mining operations in gold, silver, and copper ores. It has been said that Mr. Carhart's career was truly representative of the fast-disappearing tradition of our industrial leaders who made their own careers from the rich clay of experience.

## Cassius I. Cook

An Appreciation by W. J. Coulter

In the passing of Cassius I. Cook, general manager of the Consolidated Coppermines at Kimberly, Nev., on Dec. 22, the mining fraternity lost a well known friend in the industry. For many years Mr. Cook had suffered from an asthmatic condition and his death was attributed to complications resulting from an acute condition.

Mr. Cook was born near Portland, Oreg., June 18, 1886. He received his early education in Boise, Idaho, and graduated from the University of Idaho in 1911. In college Mr. Cook took an active part in athletics and for three years played on the football team.

After graduating from the University of Idaho, he became superintendent of the Silver City Mining and Milling Co., at Silver City, Idaho. From Silver City he went to Alaska in 1915 and later to British Columbia where he was employed by the Granby Consolidated Mining, Smelting and Power Co. In 1927 Mr. Cook left Anyox, B. C., where he was assistant mine superintendent, to accept a position as mine superintendent of Consolidated Coppermines. During the depression period, from 1932 to 1935 when Coppermines was closed down, he operated a small gold property in Grass Valley, Calif. In 1935 he went to Silverton, Colo., where he was general superintendent of the Shenandoah Dives Mining Co. until 1940 at which time he returned to Kimberly, Nev., as general manager of the Consolidated Coppermines, which position he held at the time of his death.

Mr. Cook was well known and had many friends in the mining field. He was an active member of the American Mining Congress, AIME, Colorado Mining Association, a director of the Nevada Mine Operators Association and a member of the Ely Rotary Club. Mr. Cook was also a member of the Kappa Sigma Fraternity.

The news of Mr. Cook's death comes as a shock to his many friends in the mining industry and to all who knew him.

HERSCHEL E. DENTON (Member 1946), managing director of General Petroleums Ltd., and a partner in the firm of Denton and Spencer since 1941, died on March 30 in Calgary, Alta. He was 41. Mr. Denton had a B.S. in mechanical engineering, which he achieved by alternate years of work with the Casper Oil Co. of Wyoming and attendance at New Mexico A&M. By 1938, he was production superintendent for the Anglo-Canadian Oil Co. in Calgary, and three years later joined the two firms with which he was associated until his death.

## Howard Drullard

An Appreciation by Harvey G. Bostick

Our AIME Directory notes: Drullard, Howard (Member '18) Min. Engr., Min. Machinery, 1026 Folsom St., San Francisco, Calif. Howard was proud of the AIME and his San Francisco Section affiliation.

He passed away in San Francisco on Jan. 29, of a heart attack. He was born in Buffalo, N. Y., in 1883, and attended private schools. He had a desire for mining and so became a shifter in the Second St. tunnel in Los Angeles and in the Elizabeth Lake tunnel of the Los Angeles water department. He contracted in the Ray Con. in Arizona, and subsequently managed the Hardenburg and Poundstone mines in California's Mother Lode. He also mined in Mexico and Central America.

While still a young man Howard was the victim of a blasting accident. Fortunately he pulled through with half vision in one eye. He never accepted this as handicap and this was evidenced by the fact that during the 1915 San Francisco exposition and fair, he represented five companies. Denver Rock Drill Co. was one of them, and after the closing of the Fair, Howard became affiliated with it. He was in turn Butte, Mont., manager, Salt Lake City manager, and then a representative for Gardner-Denver in Japan and Korea. Returning to the States in 1928, he attended Stanford University. In 1932 he decided to enter private business and established the firm which he managed until his demise.

This is an example of Howard's great human kindness and understanding: During his residence in Butte he became acquainted with Stephen Breckenridge, a miner totally blinded by an explosion. Encouraged by Howard to "carry on," Steve sold newspapers. Later, Steve moved to Los Angeles and has been on the corner of Fifth and Broadway for many years—selling newspapers—and is independent. Howard never failed to visit Steve during his Los Angeles calls.

Howard Drullard's counsel was kindly. His many, many friends all over the world will be saddened by his passing, but he was the type of man that will live on in memory and in spirit.

CECIL DRAKE (Member 1931), died in Taft, Calif., on Jan. 31, at the age of 49. He had worked for the Standard Oil Co. of California since 1946. With an E.M. in geology from the Colorado School of Mines, Mr. Drake went to Mexico in 1922 to work for the Eagle Petroleum Co. of Mexico, a Shell company, and remained there for eight years. Then he returned to the States to work for the Shell organization in Illinois and Oklahoma before joining Standard Oil.

Donald R. Knowlton

DONALD R. KNOWLTON (Member 1932), manager of the foreign department of the Phillips Petroleum Co., and perhaps best known for his work as director of production with the Petroleum Administration for War, died in Oklahoma City on March 9 after a short illness. He was 54. After taking his E.M. degree from Stanford University in 1924, Mr. Knowlton worked as an engineer for the Continental Oil Co. in Texas, joined the Phillips organization in 1930, becoming chief production engineer a year later. He recently stirred the business world with a magazine article on "The Semantics of Financial Reports" which censured the obscure, technical language in which financial reports are phrased.

LIONEL H. DUSCHAK (Member, 1917), professor of metallurgy at the University of California, died on Nov. 27. Born in 1882, Dr. Duschak received his A.B. degree from the University of Michigan in 1904, went on to take an M.A. and Ph.D. from Princeton four years later. With his degrees in chemistry, he taught that subject at Princeton from 1907 to 1909, then served four years as a research engineer for the Corning Glass Works and the next five years as a chemical engineer with the Bureau of Mines. Since 1921 he had been a consulting engineer, and in 1938 joined the faculty of the University of California.

CHARLES DENHAM GRIER (Member 1915), died on Dec. 2 in Johannesburg, South Africa, where he had been, since 1923, managing director of South African Cyanamid Ltd. Born in 1889 in Denver, Colo., Mr. Grier was a graduate of the Colorado School of Mines, also had an M.Sc. degree from the University of Washington. His early experience took him through the West, and then up to Alaska. The first World War found him a Second Lieutenant in the engineers. In 1922 Mr. Grier joined the American Cyanamid Co., and the following year took up residence in South Africa to manage that Company's interests there. In 1937 he took over the position he held at the time of his death. Although his main efforts dealt with cyanide production, Mr. Grier took an active interest in the whole mining and industrial development of southern Africa.

HORACE S. GULICK (Member 1916), whose career had taken him from Oklahoma A&M to the first vice-presidency of the New York Air Brake Co., died on Jan. 31 at the age of 63. Mr. Gulick received his B.S. degree from the above-named school in 1903, and within ten years had become chief chemist for the American Steel Foundries in East St. Louis, Ill. Later he was superintendent of testing and inspection at the More-Jones Brass and Metal Co., and in 1921 superintended the Ohio Brass Company's Mansfield, Ohio, plant. Six years later he assumed a similar position with New York Air Brake, remaining with the Company until his death.

ELWIN B. HALL (Member 1914), petroleum engineer and oil geologist, died in Los Angeles on Jan. 20. Mr. Hall was 57 and had been ill for three weeks prior to his death. At the time of his death he headed the E. B. Hall Co., which operated the Union Pacific oil properties at Wilmington, California. Mr. Hall was a graduate of the School of Geology of Stanford University, where he had been a three year letterman in rugby and notably proficient in other sports. He worked as a petroleum geologist for many years, and in 1937 became president of the Hall-Baker Co. in Los Angeles.

PHILIP H. HOLDSWORTH (Member 1938), for many years prominent in Oregon mining, died at his home in Seattle last Nov. 21. He was born in 1881. Back in 1908 Mr. Holdsworth was assistant superintendent for the Alaska Smelting and Refining Co. in Hadley, later went on to do mining and metallurgical work in California, Oregon, and the State of Washington. Since 1920 he had been a consulting engineer with offices in Seattle, was greatly interested in geophysical work, and made several investigations in both Oregon and Washington employing resistivity methods.

FREDERIC W. JAMES (Member 1917), died last Dec. 28 at his home in Belleville, N. J., at the age of 68. He was a vice-president and engineer at the N. P. Nelson Iron Works, Inc., in Passaic, and had been associated with the firm for 27 years. Born in St. Marys, Reading, England, he came to this country at an early age, attended Trinity School, and the Columbia School of Mines. From the

### Necrology

| Date Elected | Name | Date of Death |
|---|---|---|
| 1948 | E. Paul Keuper | December 1948 |
| 1916 | H. H. Stout | April 13, 1949 |
| 1914 | A. M. Tweedy | January 1949 |

turn of the century until he joined the Nelson organization, Mr. James had worked for nine engineering concerns, as both draftsman and engineer. He devoted twenty years to serving the Boy Scouts in his hometown, was also a member of the National Historical Society, and a frequent contributor to various engineering publications.

OTTO G. LEICHLITER (Member 1935), president of the Mudge Oil Co. of Texas, died last Sept. 8, at the age of 63. Although his professional education in mechanical and civil engineering was not acquired formally, but in home studies, Mr. Leichliter was, at the age of 22, superintending a tunneling operation for the Gold Cup Mining and Milling Co. in Colorado. Two years later he joined the Edward W. Mudge Co., becoming general manager of four affiliated companies, and building coal mines, coke ovens, blast furnaces, and developing oil properties. By 1934 he was vice-president of the Weirton Coal Co. and Union Electric Steel Co., and also held the position he retained until the time of his death.

R. JOHN LEMMON (Member 1930), died in Nenagh, Tipperary, Eire, on Jan. 26. A British subject, born in Sussex in 1878, Mr. Lemmon traveled far and wide in pursuit of his metallurgical career. He was a chemist on the Gold Coast in 1911, at work in Korea eleven years later, and within the next seven years had been a metallurgist in Brazil, Turkey, Russia, and Bolivia. In 1938 he joined Imperial Chemical Industries, Ltd., in Liverpool, and at the time of his death was a metallurgist for the Irish Exploration Co. in Tipperary.

NORMAN MACKENZIE (Member 1943), owner of the Coleville Engineering Co., Spokane, Wash., died Dec. 8 at the age of 53. Born in Canada, Mr. Mackenzie attended Manitoba College and Manitoba University, receiving his B.Sc. degree in 1919. His education was interrupted from 1914 to 1919 while he served as Lieutenant-Captain in the Canadian Engineers during World War I, leading a tunneling company in England, France, Belgium, and Germany. Varied engineering experience in this country and Canada brought him to the formation of his own company in 1936. He engineered and designed 24 rural electrification systems, carried on extensive electrical, municipal, and mining consultation activities until the time of his death. Mr. Mackenzie was also an active member of numerous professional and social groups, including the American Legion, BPOE, and the Spokane Press Club.

F. A. G. MAXWELL (Member 1936), who spent his whole professional career in the South African gold mining industry, died in Johannesburg on Dec. 26. He was 74 years old. Mr. Maxwell, a British citizen, was born in Freemont, Neb., received his education at the Colorado School of Mines, and went to South Africa immediately after graduating in 1895. He played a large part in the foundation and development of metallurgical practice on the Rand, and was consulting metallurgist to the General Mining and Finance Corp. for the past thirty-three years.

Arthur S. Nichols

ARTHUR S. NICHOLS (Member 1936), vice-president and sales manager of the Illinois Clay Products Co. for more than 23 years, died on Feb. 18. He was 48 years old. Mr. Nichols, chairman of the AIME Committee on Ceramic Materials, and chairman of the Chicago Section in 1944, was a native Chicagoan, educated at the University of Illinois. He began his career in 1922 with the Harbison-Walker Refractories Co., then became a technical adviser to the Chicago Firebrick Co. before joining the Illinois organization.

ALEXANDER G. McGREGOR (Member 1915), died on March 4 at the age of 69. Mr. McGregor had been in London for the past twenty-two years, serving as a consulting mechanical engineer to the Chester Beatty group of mining companies. To that group, he brought a formidable reputation as a designer and builder of smelting works, mining, and metallurgical plants. Some of the plants he designed and constructed include: the International Smelting Co. plant at Miami, Ariz.; the Cerro de Pasco Copper Corp's. smelting works in Peru; the Phelps-Dodge smelting units at Douglas, Ariz.; and the Inspiration C. C. Company's leaching plant. During the recent war he was a consulting engineer to the British Ministry of Aircraft Production.

Mr. McGregor had a B.S. from the University of Montana, was the author of numerous economic articles and books, among them "The Correct Economy for the Machine Age," "Collective Bargaining and Decadence," and "End Wages Conflict."

WALTER B. MILLER (Member 1916), electrical and mining engineer of Huntington, W. Va., died last September. Mr. Miller was born in 1878, attended West Virginia University and the University of Kentucky, and spent the bulk of his early career with Kentucky and West Virginia coal companies, except for a stint with the Army engineers during World War I. More recently he had been general manager for the Kentucky King Coal Co., and his last affiliation was with the Guyen Eagle Coal Co. in Huntington.

THOMAS MacDONALD ROBERTSON (Member 1948), died last Aug. 16 at the age of 23. A native of Glasgow, Scotland, Mr. Robertson graduated from the Royal Technical College in 1945, became a research metallurgist and later assistant melting shop manager in the Clydebridge steel works. He was an associate member of the West of Scotland Iron and Steel Institute, and a student member of the Institute of Metals.

THEODORE W. ROBINSON (Member 1884), who was vice-president of the Illinois Steel Co. until 1932, died on Dec. 30. Mr. Robinson had been a member and director of various public and private organizations, including positions as trustee of Northwestern University, a director of the City National Bank and Trust Co., the Illinois Bell Telephone Co., and chairman of Ditto, Inc. He was an MIT graduate, class of 1884.

WILLIAM A. ROSE (Member 1940), well known figure in the iron mining industry, died in Santa Monica, Calif., at the age of 66. Mr. Rose had been with the Pickands-Mather Co. for nearly a half-century. Born in Rochester, he received a degree in mining engineering from the University of Minnesota in 1906, became chief engineer for the Oilver Iron Mining Co., and then went to Pickands-Mather in 1913. He was appointed chief engineer there, and later assistant general manager. After a short stint in Cleveland for the Company, he retired in January 1947, and went to live in California.

A. D. SHANKLAND (Member 1917), metallurgical engineer on the staff of the operating vice-president of Bethlehem Steel Co., died Jan. 5. Of Mr. Shankland's 57 years, 35 were spent at Bethlehem. He first joined the Company as a chemist in 1914, upon graduation from Virginia Polytechnic Institute. Subsequently, he rose through the positions of metallurgy inspector, engineer of tests, and assistant general manager, to the post he was holding at the time of his death.

FREDERICK WARREN SNOW (Member 1917), president of the Vermont Copper Co., died in Hanover, N. H., on March 7. Mr. Snow had been with the Company since 1943, having served previously as general manager of the U. S. Mining and Smelting Co's. Mic-Mac mines in Quebec, and in the same capacity for the Eustis mine in Sherbrook, Que. A graduate of the University of Utah, Mr. Snow, had also spent thirteen years with the Magma Copper Co. in Superior, Ariz., and done mining and consulting work in the West and South America.

JAMES W. STARKS (Member 1945), director of the Illinois State Mines and Minerals Department, died in Springfield on Feb. 3, just seventeen days after he had taken over the post. Union members and coal operators alike had both heartily approved of his appointment last December. For the past 27 years he had been with the Peabody Coal Co., and for eight years was a mine officer in the department he came to head. He had also served four years as mine inspector in eight different counties, bringing a background of twenty-five years' varied experience to his work for the State.

DAVID R. THOMAS (Member 1904), Canadian mining engineer, died on March 4 at the age of 73, in Toronto. The British-born Mr. Thomas received his education and early training in his homeland, came to Canada in 1899 as an engineer for the Canadian Pacific Railway. Later he spent over ten years as a mine executive in Mexico, and another decade in mining, consulting, and managerial positions in Mexico, New York, and Canada, respectively. When he retired from active practice in 1930 he was a mining consultant in Toronto.

WILLIAM G. WAGNER (Member 1920), died in London, England, on March 19 at the age of 75. Mr. Wagner was managing director of George T. Holloway and Co., of London, which firm he had been with for the past forty-one years.

BAILEY WILLIS (Member 1892), seismologist and geologist of international fame, died in Palo Alto, Calif., on Feb. 19. Dr. Willis, who had made a lifelong study of earthquakes, was also a writer, lecturer, explorer, and world traveler, and extremely active until his ninety-first, and last year. A Columbia School of Mines graduate, he began his career as a mining engineer, later worked with the USGS, did research in China for the Carnegie Institution, and exploration in Argentine. In 1915 he took over Stanford University's department of geology, was forced to retire at sixty-five, but stayed on as professor emeritus until the time of his death. Just before his death he completed the second part of his two-volume biography, entitled "Friendly China."

# Proposed for Membership

**Total AIME membership on April 30, 1949, was 15,566; in addition 4187 Student Associates were enrolled.**

ADMISSIONS COMMITTEE

*James L. Head, Chairman; Albert J. Phillips, Vice-Chairman; George B. Corless, T. B. Counselman, Ivan A. Given, George C. Heikes, Richard D. Mollison, and Philip D. Wilson.*

*Institute members are urged to review this list as soon as the issue is received and immediately to wire the Secretary's office, night message collect, if objection is offered to the admission of any applicant. Details of the objection should follow by air mail. The Institute desires to extend its privileges to every person to whom it can be of service but does not desire to admit persons unless they are qualified.*

*In the following list C/S means change of status: R, reinstatement; M, Member; J, Junior Member; AM, Associate Member; S, Student Associate; F, Junior Foreign Affiliate.*

ALABAMA

*Birmingham* — SPARF, CHARLES ROY. (R,C/S—S-AM). Explosive serviceman, Hercules Powder Co.

ARIZONA

*Klondyke*—WILSON, GLEN BAYHA. (C/S—J-M). Mine superintendent, Athletic Mining Co.

*Morenci*—JACOBY, DWIGHT CLARK. (C/S—S-J). Hydrographic engineer, Phelps Dodge Corp., Morenci branch.

CALIFORNIA

*Arcadia* — DRAPER, DARRELL WELLINGTON. (M). Process service representative, Linde Air Products Co.

*Bakersfield* — CHRISTENSEN, JOHN ALEXANDER. (M). Geologist, British-American Oil Producing Co.

*Berkeley*—McCLELLAND, THOMAS HUTCHISON. (R,C/S—AM-M). Field manager, Asnazú Gold Dredging, Ltd.

*Fontana* — SAUSSAMAN, JOHN DANIEL. (M). Superintendent, blast furnace dept., Kaiser Co.

*Los Angeles* — TIPTON, KENNETH AMESTOY. (C/S—S-J). Insurance agent and broker, Kenneth E. Tipton Insurance Agency.

*Maywood* — BOWDEN, CARL B. (C/S—S-J). Assistant petroleum engineer, Union Oil Co. of California.

*Pittsburg* — CALDWELL, THOMAS EDGERTON. (M). Works metallurgist, Pittsburg works, Columbia Steel Co.

COLORADO

*Cherry Hills Village* — NICHOLSON, JAMES DOUGLASS. (M). General manager, The Mine & Smelter Supply Co.

*Leadville* — METZGER, GUINN EDWARD. (C/S—S-J). Junior metallurgist, Resurrection Mining Co.

*Rangely* — LEUZINGER, LESLIE ADOLPH. (C/S—S-J). Field engineer, Union Pacific Railroad Co. oil development, c/o The Texas Co.

DISTRICT OF COLUMBIA

*Washington* — BRABANT, PAUL HENRI. (M). Consulting engineer on Chinese mines, Pierce Management, Inc.

IDAHO

*Wallace*—HAALAND, OTTO ELMER. (C/S—AM-M). Mining engineer, Spokane-Idaho Mining Co. HAMILTON, WOODMAN CLARK, JR. (J). Shift boss, Day Mines, Inc.

ILLINOIS

*Chicago* — BIDDLE, GEORGE JOSEPH. (M). Assistant sales manager, Illinois Clay Products Co. JAIN, PADAM PRASAD. (M). Engineering supervisor, Killium & Co. SIREL, I. ALEXIS. (M). Metallurgist, Youngstown Sheet & Tube Co. SLOMER, JOSEPH J. (M). Supervisor, design-hydraulics, Goodman Mfg. Co.

*Danville*—MERLE, JAMES JOSEPH. (C/S—J-M). Assistant preparation manager, Ayrshire Collieries Corp.

*Gillespie* — HUBBART, CURTIS QUENTIN. (R,C/S—S-M). Mining engineer, Superior Coal Co.

*Oakwood*—MULLINS, RICHARD A. (M). Chief chemist, Ayrshire Collieries Corp.

*Peoria* — ANDERSON, ROBERT GRANT PHILLIP. (C/S—S-J). College graduate trainee, Caterpillar Tractor Co.

*Salem*—LOVE, RICHARD WILLIAM. (M). District petroleum engineer, The Texas Co. MULLINS, JESSE FRANK. (J). Petroleum engineer trainee, The Texas Co.

INDIANA

*Bloomington* — CALLAGHAN, EUGENE. (R,C/S—J-M). Professor of economic geology, Indiana University.

*West Lafayette*—HOPPE, ALBERT WILLIAM. (J). Instructor of metallurgy, Purdue University.

KENTUCKY

*Benham*—NEWMAN, ELMER KIMBER. (R-M). Chief engineer, International Harvester Co.

LOUISIANA

*Minden* — LARSON, KENNETH HENRY. (C/S—S-J). Junior computer, Stanolind Oil & Gas Co.

MASSACHUSETTS

*Roslindale*—PAYNTON, WILLIAM C. (C/S—S-J). Staff member of metallurgy project, MIT.

MICHIGAN

*Detroit* — STICKEL, JOHN FREDERICK, JR. (C/S—S-J). Geological engineer, Wesley, Bedford & Stickel.

*Marquette*—DeHAAS, GORDON TIFFANY. (C/S—S-J). Sales engineer, C. T. DeHaas Co.

MINNESOTA

*Hibbing* — McDERMOTT, WILLIAM FRANCIS. (J). Mechanical engineer, W. S. Moore Co.

*Parkville*—VAN EVERA, JAMES W., JR. (C/S—J-M). Chief mine engineer, Inter-State Iron Co.

MISSISSIPPI

*McComb* — MARTIN, WALTER OBIER. (C/S—S-M). Reservoir engineer, The Texas Co.

MISSOURI

*Kirkwood* — MASSMANN, ALBERT P. (M). In charge of preparation, Sinclair Coal Co. QUINN, MAURICE L. (M). Electrical engineer, Sinclair Coal Co.

*St. Louis*—SCALLY, JOSEPH EDWARD. (R,C/S—J-M). Vice-president, Harmony Oil Corp.

MONTANA

*Cut Bank*—FLUGSTAD, JOHN BUTLER. (RC/S—S-M). District engineer, The Texas Co.

NEW JERSEY

*North Plainfield*—COOK, CHARLES ROSCOE, JR. (C/S—S-J). Research metallurgist, Titanium Division, National Lead Co.

NEW MEXICO

*Buckeye*—DENSON, JACK McVAY. (C/S—S-J). Petroleum engineer trainee, The Texas Co.

*Carlsbad*—BINSWANGER, TOLSTOY LEO. (M). Extra supervisor, U. S. Potash Co.

*Hobbs*—BEARLY, MARION FRANK. (J). Student engineer, Gulf Oil Corp.

NEW YORK

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No Directory will be published in 1949, so the following list of AIME officers and committees is being printed in the three journals. It includes the committees of the Mineral Industry Education and Mineral Economics Divisions. Committees of other Divisions appear in Section 1 of the Branch journals as follows:

| *Magazine* | *Division* |
|---|---|
| MINING ENGINEERING | Coal<br>Industrial Minerals<br>Extractive Metallurgy<br>Minerals Beneficiation<br>Mining, Geology and Geophysics (Not yet appointed) |
| JOURNAL OF METALS | Institute of Metals<br>Iron and Steel<br>Extractive Metallurgy |
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Holds meeting first Friday of each month except July and August

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**Howard P. Sherman**, Vice-Chairman

**Joseph A. Mecia**, Vice-Chairman

**L. A. Grant**, Secretary-Treasurer; Day Mining Co., Box 795, Wallace, Idaho

**Harold Kirkemo**, Assistant Secretary, 466 Peyton Bldg., Spokane 8, Wash.

**Snake River Subsection**

**Joseph A. Mecia**, Vice-Chairman

**Harry W. Marsh**, Assistant Secretary; Idaho Min. Assoc., 304 Capitol Securities Bldg., Boise, Idaho

### CONNECTICUT

Established Sept. 30, 1947

**Lewis E. Thelin**, Chairman

**Lloyd E. Raymond**, Vice-Chairman

**David H. Thompson**, Secretary-Treasurer, The American Brass Company, Waterbury 88, Conn.

**Committee Chairmen**

George F. Donahue, Membership

Theodore H. Carlson, Publicity

**Director-at-Large**

Walter R. Hibbard, Jr.

### DELTA

Established Sept. 18, 1946

Meets second Tuesday in the month except during June, July, and August

**E. N. Dunlap**, Chairman

**H. M. Krause, Jr.**, Vice-Chairman

**Charles R. Blomberg**, Vice-Chairman

**Fred E. Simmons, Jr.**, Secretary-Treasurer; 1901 American Bank Bldg., New Orleans, La.

**J. P. Ratliff, Jr.**, Journal Secretary

**Directors**

| | |
|---|---|
| A. Claudet | H. C. Petersen |
| B. C. Craft | E. G. Robinson |

J. C. Posgate

**Chairmen of Committees**

A. Claudet, Program

E. N. Van Duzee, Activities

H. M. Krause, Jr., Membership

P. J. Ratliff, Publicity

C. R. Blomberg, House

Dan Payne, Co-Chairman, Publicity

### DETROIT
Established Feb. 18, 1936

Holds meetings third Monday of each month, except June through September

**R. F. Mather,** Chairman
**F. P. Bens,** Vice-Chairman
**R. D. Chapman,** Secretary, Engineering Div., Chrysler Corp., 12800 Oakland Ave., Detroit, Mich.
**B. B. Beckwith,** Treasurer

**Executive Committee**

E. W. Engle, Jr. — C. L. Raynor
R. N. Lynch — C. A. Siebert
W. B. McFerrin — E. W. Weinman

### EAST TEXAS
Established April 18, 1940

Meets the second Tuesday of each month except July, August, and September

**J. M. Shepherd,** Chairman
**W. W. Leonard,** Vice-Chairman
**R. F. Beery, Jr.,** Secretary-Treasurer Shell Oil Co., Inc., Box 32, Kilgore, Texas

John S. Bell — W. M. Jones
L. H. Dial — P. J. Lehnhard
R. M. Hess — R. T. Wade

### EL PASO METALS
Established March 25, 1927

Meets second Wednesday each month

**Edward M. Tittman,** Chairman
**J. E. Despins,** Vice-Chairman
**Guy E. Ingersoll,** Secretary-Treasurer Texas College of Mines and Metallurgy, El Paso, Texas

**Directors**

Perry A. Alers — A. F. Horle
A. A. Collins — William W. Long
Hugh M. Craigie — R. J. Mellen
E. W. Donahue — W. S. Strain
T. J. Woodside

### GULF COAST
Established Dec. 13, 1935

Meets third Tuesday of each month

**Owen F. Thornton,** Chairman
**Ernest B. Miller, Jr.,** Vice-Chairman
**A. B. Stevens,** Vice-Chairman
**George Fancher,** Vice-Chairman
**Everett F. Stratton,** Secretary-Treasurer, P. O. Box 2175, Houston, Texas

**Board of Directors**

Fred M. Nelson, '50 — G. D. Robertson, '50
George L. Nye, '49 — L. V. Uhrig, '49
Ralph W. Wilson, '49

### KANSAS
Established Nov. 17, 1948

**V. J. Mercier,** Chairman

**District Vice-Chairmen**

W. C. Pearson, Western Kansas
Gene E. Abernathy, Eastern Kansas
Daniel H. Sholtus, Wichita

**W. F. Brown,** Secretary-Treasurer Dowell Incorporated, 519 Union National Bank Bldg., Wichita 2, Kansas

**Directors**

P. T. Amstutz, Jr. — C. F. Weinaug
W. R. Warren — P. A. Witherspoon, Jr.

### LEHIGH VALLEY
Established March 27, 1924

**F. E. Van Voris,** Chairman
**R. T. Gallagher,** Vice-Chairman
**B. J. Larpenteur,** Vice-Chairman
**R. B. Hoy,** Vice-Chairman
**C. G. Tebelman, Jr.,** Secretary Bethlehem Steel Co., Mining Dept., Bethlehem, Pa.
**Robert G. Peets,** Treasurer

**Managers**

W. S. Cumings — M. L. Fuller
J. W. Guider

**Committee Chairmen**

W. S. Cumings, Program
M. L. Fuller, Nominating
E. R. Gault, Membership
J. F. Libsch, Student Prize Award
D. Lyons, Hospitality

### MID-CONTINENT
Established Dec. 28, 1917

**John P. Hammond,** Chairman
**J. Murray Walker,** First Vice-Chairman
**R. H. Gwinner,** Second Vice-Chairman
**Roy H. Smith,** Secretary-Treasurer Stanolind Oil and Gas Co., Box 591, Tulsa, Okla.

**Executive Board**

C. B. Carruthers — Jack Tarner
Meyer H. Dubrow — A. W. Walker
J. M. Wanenmacher

**Ex officiis**

R. C. Earlougher — P. P. Manion, Jr.
P. E. Fitzgerald — C. V. Millikan

### MINNESOTA
Established Dec. 20, 1920

Annual meeting second week in January; other meetings as called by the officers

**W. L. Taylor,** Chairman
**Grover E. LeVeque,** Vice-Chairman
**Charles J. O'Connell,** Secretary-Treasurer, 400 West Franklin Ave., Minneapolis 5, Minn.

**Directors**

R. H. B. Jones — Edward P. Scallon
Richard W. Whitney

### MONTANA
Established Oct. 17, 1913

Meetings held the fourth Tuesday of the month except July and August

**J. Hollis McCrea,** Chairman
**J. P. Spielman,** Vice-Chairman
**F. W. Strandberg,** Secretary-Treasurer Anaconda Copper Mining Co., 421 Hennessy Bldg., Butte, Mont.

**Executive Committee**

Kuno Doerr, Jr. — E. C. Van Blarcom

**Committee Chairmen**

George T. Hanson, Program
Orrin D. Weeks, Membership
H. G. Satterthwaite, Nominating
Morgan H. Wright, Student Awards
William J. Waylett, Professional Development of Junior Members

### NEVADA
Established Jan. 21, 1916

**Louis D. Gordon,** Chairman
**John C. Kinnear, Jr.,** Vice-Chairman
**Andrew C. Rice,** Secretary-Treasurer Box D, University Station, Reno, Nev.

**Executive Committee**

Norman T. Annett — J. Ray Coulter
Samuel S. Arentz, Jr. — John M. Heizer

**Reno Branch**

Luncheon meeting the first Thursday of every month

**Albin C. Johnson,** Chairman
**Albert Silver,** Secretary-Treasurer

### NEW YORK
Established May 19, 1911

Holds monthly meetings except February, June, July, August, and September

**Theodore B. Counselman,** Chairman
**Thomas G. Moore,** Past Chairman
**Robert H. Ridgway,** Vice-Chairman
**John T. Sherman,** Vice-Chairman
**P. Malozemoff,** Secretary; Newmont Mining Corp., 14 Wall St., New York 5, N. Y.
**Fred D. Kay,** Treasurer

**Committeemen**

James Douglas — Louis C. Raymond
Richard D. Mollison — James S. Vanick
Philip D. Wilson

### NORTH PACIFIC
Established March 28, 1913

Meets third Thursday of each month except June, July, and August

**Kenneth H. Anderson,** Chairman
**Lee W. Heinzinger,** Vice-Chairman
**W. C. Leonard,** Secretary-Treasurer Tacoma Smelter, American Smelting & Refining Co., 3709 No. Madison, Tacoma, Wash.

**Drury A. Pifer,** Corresponding Secretary

**Counselors**

Paul T. Benson — E. R. McMillan
H. F. Yancey

### NORTH TEXAS
Established May 16, 1945

**Don L. Harlan,** Chairman
**J. A. Slicker,** Vice-Chairman for Fort Worth
**J. A. Crichton,** Vice-Chairman for Dallas
**I. E. Curtis,** Vice-Chairman for Wichita Falls
**S. V. McCollum,** Secretary-Treasurer Continental Oil Co., 1710 Fair Bldg., Fort Worth 2, Texas

**Directors**

D. H. Clewell — Tom E. Morton
W. J. Jackson — W. D. Sorrells
E. E. Merkt, Jr. — L. P. Wharton

### OHIO VALLEY
Established Nov. 19, 1920

**William A. Mueller,** Chairman
**Donald W. Scott,** Vice-Chairman
**John H. Melvin,** Secretary-Treasurer State Geologist, Ohio Geological Survey, Ohio State University, Columbus 10, Ohio
**Frank G. Smith,** Assistant Secretary-Treasurer

**Chairmen**

**R. J. Lund,** Program Committee
**Homer Faust,** Membership Committee
**Cloyd A. Snavely,** Representative, Junior Members
**John A. Schumann,** Representative, Student Associates
**Clyde Williams,** National Director

**Area Representatives**

C. E. Bales, Portsmouth
W. B. Berwald, Findlay
Robert S. Bower, Cincinnati
C. R. FonDersmith, Middletown
George R. Long, Dayton
James D. Reilly, St. Clairsville
Max A. Tuttle, Indianapolis
R. M. Woodward, Newark

### OKLAHOMA CITY
Established Feb. 18, 1947

**Lincoln F. Elkins,** Chairman
**Nico Van Wingen,** Vice-Chairman
**Henry Waszkowski,** Vice-Chairman
**Martin O. Hegglund,** Secretary-Treasurer, Stanolind Oil and Gas Co., 2003 First National Bldg., Oklahoma City, Okla.

**Directors**

R. J. Beams — C. E. Clason — H. R. Sells

### OREGON
Established April 22, 1921

Meets third Friday of each month except during summer months

**H. M. Dole,** Chairman
**J. H. Leary,** Vice-Chairman
**S. H. Lorain,** Past Chairman
**A. O. Bartell,** Secretary-Treasurer, 321 Platt Bldg., Portland 5, Oregon

**Executive Committee**

D. H. Beetem — F. W. Libbey

### PENNSYLVANIA-ANTHRACITE
Established Feb. 17, 1914

Spring meeting, April; Summer meeting, July; Fall meeting, October
Meetings held alternately at Pottsville, Hazleton, Wilkes-Barre, and Scranton

**William B. Geise,** Chairman
**George A. Roos,** Vice-Chairman
**Floyd S. Sanders,** Secretary-Treasurer, Goodman Mfg. Co., P. O. Box 151, 35 New Bennett St., Wilkes-Barre, Pa.

**Executive Committee**

H. J. Connolly — F. E. Kudlich
W. E. Conroy — H. D. Kynor
C. Evans, Jr. — Earl W. Lamb
C. A. Gibbons — J. C. MacCartney
Edward Griffith — H. W. Montz
D. C. Helms — W. C. Muehlhof
Wilmot Jones — Walter B. Petzold
Joseph E. Ward

### PERMIAN BASIN
Established Nov. 14, 1945

**Thomas C. Frick,** Chairman
**W. N. Little,** Vice-Chairman
**J. M. Moore,** Secretary-Treasurer; Dist. Engr., Dowell, Incorporated, Box 1858, Midland, Texas

**Directors**

| | |
|---|---|
| Burton Atkinson | W. N. Little |
| William L. Crothers | Lamar Lunt |
| Thomas C. Frick | J. M. Moore |

**Committee Chairmen**

W. N. Little, Program
Joe Chastain, Membership

### PHILADELPHIA
Re-established March 15, 1944

**F. B. Foley,** Chairman
**A. W. Grosvenor,** Vice-Chairman
**A. L. Jamieson,** Vice-Chairman
**F. J. Dunkerley,** Secretary-Treasurer 247 Engineering Bldg., University of Pennsylvania, Philadelphia 4, Pa.

**Executive Committee**

| | |
|---|---|
| C. B. Allen | D. I. Finch |
| R. M. Brick | Leopold Pessel |

### PITTSBURGH
Established 1920

**H. P. Greenwald,** Chairman
**G. J. Donaldson,** Vice-Chairman
**George H. Enzian,** Secretary; Jones & Laughlin Steel Corp., 40 Longworth St., Pittsburgh 7, Pa.
**R. F. Miller,** Treasurer

| | |
|---|---|
| W. L. Affelder | M. F. Hawkes |
| N. G. Alford | K. C. Heald |
| M. D. Cooper | E. H. Hollingsworth |
| D. H. Davis | S. Krickovic |
| G. H. Deike | E. Leatham |
| G. R. Fitterer | J. T. Ryan, Jr. |
| M. G. Gulley | R. E. Sherrill |

J. C. Sullivan

**Ex officiis**

| | |
|---|---|
| H. N. Eavenson | S. A. Taylor |

**Open-Hearth Committee**

**A. W. Thornton,** Chairman
**J. F. Pollack,** Secretary
**H. E. Johnson,** Executive Secretary
**C. Longenecker,** Treasurer

### ST. LOUIS
Established May 23, 1913

**Herbert A. Franke,** Chairman
**H. A. Neustaedter,** Vice-Chairman
**N. A. Stockett,** Past Chairman
**Fred J. Meek,** Secretary-Treasurer American Zinc Co. of Illinois, Box 495, East St. Louis, Ill.
**K. A. Phillips,** Program Chairman

**Executive Committee**

| | |
|---|---|
| W. R. Chedsey | John D. Kerr, Jr. |
| J. C. George | Gill Montgomery |

Curtis L. Wilson

### SAN FRANCISCO
Established June 26, 1913

Meets second Wednesday of each month except June, July, and August: and Monday noons for luncheon at Engineers' Club

**Edward H. Wisser, Chairman**
**Philip R. Bradley, Jr.,** Vice-Chairman
**George H. Playter,** Secretary-Treasurer Room 820, 405 Montgomery St., San Francisco 4, Calif.

**Executive Committee**

| | |
|---|---|
| P. R. Bradley, Jr. | W. W. Mein, Jr. |
| W. C. Collyer | Walter L. Penick |
| Carlton D. Hulin | George H. Playter |

Edward H. Wisser

**Committee Chairmen**

Philip R. Bradley, Jr., Program
J. Ward Downey, Membership
Frank S. Hudson, Student Contact
Olaf P. Jenkins, Student Prize
Lawrence B. Wright, Licensing
Granville S. Borden, Entertainment and Hospitality
Worthen Bradley, Advisory
Ira B. Joralemon, Nominating
William C. Collyer, Finance
Edward W. Bullard, Advisory Committee of Engineering Societies Personnel Service
Philip R. Bradley, Jr., Legislative
Edward H. Wisser, Engineering Council

### SOUTHEAST
Established Feb. 18, 1936

**J. C. Gray,** Chairman
**William C. Chase,** First Vice-Chairman
**W. C. McKenzie,** Second Vice-Chairman
**Reynold Q. Shotts,** Secretary-Treasurer; University of Alabama, Box 1526, University, Ala.

**Committee Chairmen**

E. H. Rose, Program
Howard Cobb, Membership and Attendance
G. T. Bator, Student Relations and the Development of Junior Engineers
Ronald F. Crawford, Publicity
Neil O. Johnson, Entertainment
Francis H. Crockard, Student Counselor

### SOUTHERN CALIFORNIA
Established May 23, 1913

**Harold J. Clark,** Chairman
**H. B. Menardi,** Vice-Chairman for Mining
**Paul Andrews,** Vice-Chairman for Petroleum
**L. W. Chasteen,** Secretary, 617 W. 7th St., Los Angeles 14, Calif.
**W. H. Geis,** Treasurer

| | |
|---|---|
| Thomas Clements | John R. McMillan |
| Richard H. Jahns | George W. Nilsson |
| C. T. McClure | Dean H. Sheldon |

Stuart H. Ingram, Past Chairman

**Committee Chairmen**

Nicholas A. D'Arcy, Jr., Membership
Paul Andrews, Programs and Legislative
Richard L. Parsons, Student Awards
Stuart H. Ingram, Nominating
Leo Schapiro, Institute of Metals and Iron and Steel Divisions
Ian Campbell, Industrial Minerals Division
George D. Dub, Mining and Milling

**Junior Division**

C. T. McClure, Chairman
I. I. Dagan, Secretary
R. L. Parsons, Treasurer

**Committee Chairmen**

N. M. Norman, Program
I. A. Marshall, Membership

### SOUTHWEST TEXAS
Established Sept. 18, 1946

Meets third Wednesday of each month except July and August

**Raoul J. Bethancourt,** Chairman
**Charles Snelson,** Vice-Chairman
**R. C. Granberry,** Secretary-Treasurer Humble Oil and Refining Co., Corpus Christi, Texas

**Directors**

| | |
|---|---|
| Barrett Booth | H. N. Lyle |
| Emil Bowers | Harold Moseley |

Lee J. Thronson

### SOUTHWESTERN NEW MEXICO
Established Sept. 30, 1947

Holds meeting second Wednesday in January, April, July, and October

**Joseph H. Taylor,** Chairman
**F. C. Green,** First Vice-Chairman
**Leo H. Duriez,** Second Vice-Chairman
**W. R. Storms,** Secretary-Treasurer U. S. Bureau of Mines, Silver City, N. Mex.

**Committee Chairmen**

John G. Reilly, Membership
T. A. Snedden, Program

### TRI-STATE
Established May 27, 1926

**Harold A. Krueger, Chairman**
**Ernest Blessing,** Vice-Chairman
**J. C. Stipe,** Secretary-Treasurer, 715 E. 15th St., Baxter Springs, Kans.

**Directors**

| | |
|---|---|
| O. W. Bilharz | Elmer Isern |
| Ernest Blessing | H. A. Krueger |
| F. J. Cuddeback | J. P. Lyden |
| G. M. Fowler | C. Y. Thomas |

**Committee Chairmen**

S. S. Clarke, Program
Ernest Blessing, Membership

### UPPER PENINSULA
Established Oct. 25, 1918

**H. S. Peterson,** Chairman
**Roy W. Drier,** Secretary-Treasurer Michigan College of Mining and Technology, Houghton, Mich.

**Executive Committee**

| | |
|---|---|
| C. W. Allen | W. E. Seppansen |
| E. C. Carlson | D. L. Watts |

**Advisory Committee**

| | |
|---|---|
| Roy W. Drier | Grover Holt |

### UTAH SECTION
Established April 24, 1914

Meets third Thursday of each month, September to May inclusive

**J. C. Landenberger, Jr., Chairman**
**Byron E. Grant,** Vice-Chairman
**R. C. Cole,** Secretary-Treasurer Pacific National Life Bldg., Salt Lake City 1, Utah

**Executive Committee**

| | |
|---|---|
| C. J. Christensen | M. B. Kildale |
| J. M. Ehrhorn | W. G. Rouillard |

**Committee Chairmen**

J. K. Richardson, Membership
Burt B. Brewster, Publicity
Robert S. Lewis, Student Affairs
K. Fritz Eilers, Entertainment

### WASHINGTON, D. C.
Established June 21, 1918

Meets generally third Tuesday of the month except June, July, and August

**Thomas H. Miller,** Chairman
**E. W. Ellis,** Vice-Chairman for D. C.
**C. J. Williamson,** Vice-Chairman for Md.
**E. J. Lintner,** Vice-Chairman for Va.
**Forrest T. Moyer,** Secretary-Treasurer U. S. Bureau of Mines, Room 1364, Interior Bldg., Washington 25, D. C.

**Executive Committee**

| | |
|---|---|
| John J. Croston | H. I. Smith |

**Member of President's Advisory Council**

S. Power Warren

### WYOMING
Established May 16, 1930

Regular meetings held quarterly; special meetings when speakers available.

**I. M. Charles,** Chairman
**M. M. Fidlar,** Vice-Chairman
**J. H. Quay,** Secretary-Treasurer; Union Pacific Coal Co., Rock Springs, Wyo.

**Executive Committee**

| | |
|---|---|
| I. N. Bayless | C. C. Boley |

H. C. Livingston

## FOREIGN

### PHILIPPINE
Established Jan. 20, 1939

**Homer A. Mann,** Chairman
**M. M. Aycardo, Jr.,** Secretary-Treasurer; International Engineering Corp., Soriano Bldg., 3rd Fl., Manila, P. I.

**Finance Committee**

| | |
|---|---|
| Steve Arick | G. J. Scheuermann |

**Program Committee**

| | |
|---|---|
| N. A. Fittinghoff | G. D. Strachan |

### RIO DE JANEIRO (BRAZIL)
Established April 17, 1936

**E. de Macedo Soares S.,** Chairman
**A. I. de Oliveira,** Vice-Chairman
**A. H. Garner,** Vice-Chairman
**Sylvio Froes Abreu,** Secretary; Instituto Nacional de Tecnologia, Rio de Janeiro, Brazil

# Officers
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## 1949

**UNIVERSITY OF ALABAMA**
University, Ala.
*Mining and Metallurgical Society**
**G. L. Roberts**, President
**T. G. Patterson**, Vice-President
**B. B. Copeland**, Treasurer
**K. F. Stark**, Secretary
**G. T. Bator**, Faculty Sponsor
**F. H. Crockard**, Counselor

**UNIVERSITY OF ALASKA**
College, Alaska
*Mining Society**
**Daniel A. Jones**, President
**Robert L. Marovelli**, Vice-President
**Edward T. Barnes**, Secretary
**Frederick F. Kohls**, Treasurer
**Earl H. Beinstline**, Faculty Sponsor
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**UNIVERSITY OF ARIZONA**
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*Miners' Society**
**Robert I. Williams**, President
**Edwin B. King**, Vice-President
**Robert O. Wenzel**, Treasurer
**Arthur E. Himebaugh**, Secretary
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Birmingham, Ala.
*The Student Geological Society of Birmingham-Southern College**
**Edward E. Walters**, President
**Audley W. Downs**, Vice-President
**Howard H. Odiorne**, Secretary
**Abner B. Chapman**, Treasurer
**J. Allen Tower**, Faculty Sponsor

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*Mining Association*
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**Val L. Freeman**, Vice-President
**Ronald N. Skow**, Secretary
**Crawford E. Jacobsen**, Treasurer
**Bernard York**, Faculty Sponsor
**B. A. Gould**, Counselor

**UNIVERSITY OF CALIFORNIA AT LOS ANGELES**
Los Angeles, Calif.
*Student Chapter, AIME**
(Inactive)

**CARNEGIE INSTITUTE OF TECHNOLOGY**
Pittsburgh, Pa.
*The Metals Society*
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**John Brown, Jr.**, Vice-President and Treasurer
**Michael Stavish**, Secretary
**Malcolm F. Hawkes**, Faculty Sponsor
**Max Gensamer**, Counselor

**CASE INSTITUTE OF TECHNOLOGY**
Cleveland, Ohio
*Pick and Shovel Club**
**D. E. Tanger**, President
**F. F. Awig**, Vice-President
**R. C. Hall**, Secretary
**R. T. Bubsey**, Treasurer
**Gerald M. Cover**, Faculty Sponsor

**UNIVERSIDAD CENTRAL**
Caracas, Venezuela
*Asociacion Venezolana de Estudiantes de Geologia**
(Inactive)

**THE CITY COLLEGE OF NEW YORK**
New York, N. Y.
*C. C. N. Y. Student Chapter, AIME**
**Herbert Feely**, President
**Jack Tarr**, Vice-President
**Julius Jettelson**, Secretary
**Seymour Feerst**, Treasurer
**Daniel T. O'Connell**, Faculty Sponsor
**Benjamin F. Tillson**, Counselor

**COLORADO SCHOOL OF MINES**
Golden, Colo.
*Student Chapter of AIME**
**Herman Knight**, President
**Bill Baker**, Secretary-Treasurer
**Harvey W. Smith**, Public Relations Chairman
**T. A. Hoy**, Director
**Jack Dempsey**, Director
**George W. Heim**, Faculty Sponsor

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New York, N. Y.
*Thomas Thornton Read Society of the Columbia School of Mines**
**Robert C. Musa**, President
**George R. Prescott**, Vice-President
**Joseph F. Brown**, Treasurer
**Roger D. Lopez**, Secretary
**Seymour Goodman**, Corresponding Secretary
**John C. Fox**, Faculty Sponsor
**Felix E. Wormser**, Counselor

**CORNELL UNIVERSITY**
Ithaca, N. Y.
*Cornell Metallurgical Society*
**Nicholas Sheptak**, President
**Albert H. Moon**, Vice-President
**Paul L. Widener**, Secretary
**Robert L. Folkman**, Treasurer
**J. L. Gregg**, Faculty Sponsor
**Stanley M. Norwood**, Counselor

*Student Chapter, AIME. Membership composed of Student Associates of the AIME.

**DRURY COLLEGE**
Springfield, Mo.
*Drury Rockhounds**
(Inactive)

**ESCUELA NACIONAL DE INGENIEROS**
Mexico, D. F.
*Sociedad Andres M. Del Rio**
(Inactive)

**UNIVERSITY OF IDAHO**
Moscow, Idaho
*Associated Miners*
**Phillip A. Beeson**, President
**Donald Gordon Dahle**, Vice-President
**Arthur Guy Randall**, Secretary-Treasurer
**Joseph Newton**, Faculty Sponsor

**UNIVERSITY OF ILLINOIS**
Urbana, Ill.
*Mineral Industries Society*
**Edward John Sperr**, President
**Norbert B. Blaski**, Vice-President
**Beverly Solliday**, Secretary
**Verle B. Utzinger**, Treasurer
**William R. Chedsey**, Faculty Sponsor
**Paul R. Nichols**, Counselor

**ILLINOIS INSTITUTE OF TECHNOLOGY**
Chicago, Ill.
*Student Chapter, AIME**
**Edward Murway**, President
**Robert Domagala**, Secretary
**O. Zmeskal**, Faculty Sponsor
**L. F. Mondolfo**, Faculty Sponsor
**T. S. Washburn**, Counselor

**IOWA STATE COLLEGE**
Ames, Iowa
*Iowa State Mining Society**
**Lloyd Daniel Brownson**, President
**Donald D. Turner**, Vice-President
**Edgar A. Perry**, Secretary-Treasurer
**Charles O. Frush**, Faculty Sponsor

**UNIVERSITY OF KANSAS**
Lawrence, Kansas
*University of Kansas Student Chapter AIME**
**Wayne C. Capron**, President
**Kenneth O. Austin**, Vice-President
**Edward B. Harry**, Secretary
**James C. Henderson**, Treasurer
**Eugene A. Stephenson**, Faculty Sponsor

**UNIVERSITY OF KENTUCKY**
Lexington, Ky.
*Norwood Mining and Metallurgical Society**
**Ralph W. Preston, Jr.**, President
**Harry L. Kirkpatrick**, Vice-President
**Everett A. Wick**, Secretary
**Harry L. Washburn**, Treasurer
**C. S. Crouse**, Faculty Sponsor
**H. Comer Wolf**, Counselor

**LAFAYETTE COLLEGE**
Easton, Pa.
*John Markle Society*
**E. Nelson Strang,** President
**Channing B. Mould,** Vice-President
**John M. Siergiej,** Secretary-Treasurer
**Bernard J. Fischer,** Faculty Sponsor

**LEHIGH UNIVERSITY**
Bethlehem, Pa.
*Howard Eckfeldt Mining and Geological Society*
**David Ford,** President
**Douglas Sammack,** Vice-President
**Malcolm Wane,** Secretary
**John Joyce,** Treasurer
**H. R. Gault,** Faculty Sponsor

**LOUISIANA STATE UNIVERSITY**
University, La.
*Student Chapter, AIME**
**James W. Law,** President
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# What Is Metallurgy?

JOHN CHIPMAN,* Member AIME

There is no better way of paying tribute to the memory of a scientist than by developing and carrying forward those ideas which he has contributed to science and which are for us the very essence of his immortality. For a lecturer who has not had the great privilege of studying under Professor Howe or even of knowing him in person, these ideas must be transmitted through the printed word. It is our great good fortune that Professor Howe left to us a rich heritage of publication, not only in his classic monograph on the "Metallography of Steel and Cast Iron" but in a wealth of earlier books and papers in the transactions of this Institute and of other scientific and engineering bodies. An outstanding characteristic of this published record is the great breadth of interest and of vision which it portrays. His was not a narrow specialization in only the scientific aspects of ferrous metallography. On the contrary many of his important contributions had to do with a far broader field of metallurgical endeavor. He insisted that his students be well grounded in the fundamentals underlying the whole field and not led into the narrow groove of specific applications. Among his first major publications we find papers on copper smelting, extraction of nickel, the efficiency of fans and blowers, thermic curves of blast furnaces, the cost of coke, and the manufacture of steel. These are the papers of a metallurgical engineer and it was among engineers that Henry Marion Howe made his early and well-merited reputation.

These early engineering contributions display very clearly the strongly scientific inclination of their author. The classic work on "The Metallurgy of Steel" published in 1890 contains a thorough and critical discussion of all that was known at the time concerning the alloys of iron and of what we would now call the physical metallurgy of steel. In addition it describes steelmaking processes in use and some that had become obsolete, and points out in critical fashion the reasons for success and failure. Steel mill design and layout were included as well as some pertinent discussion of refractories. The book is indeed an embodiment of one of Howe's outstanding characteristics—breadth. It is both the science and the engineering of steel production as known in that day.

One of Howe's earliest technical papers was entitled "What is Steel?" That was nearly seventy-five years ago when many new processes and new kinds of steel were being developed. The time was ripe for such a question and the answers which Howe was able to give were helpful in understanding the phenomena of heat treatment. Twenty-five years ago Professor Sauveur repeated the question as the title of the first Henry Marion Howe Memorial Lecture. It seemed to him that this question, "What is Steel?," had served as Howe's motto throughout the remainder of his life.

Today I shall present for your consideration a question of another sort: "What is Metallurgy?" Perhaps it is not too much to hope that in the answer we may obtain a clearer and possibly broader view of the nature of our science and our profession. The time is ripe for giving careful consideration to what we mean by metallurgy. If our Metals Branch is to become in fact an American Institute of Metallurgical Engineers, it is essential that we understand what is meant by metallurgical engineering. I am convinced that the best interests of the profession have not been served by a narrow interpretation of these terms. We must now place emphasis on the breadth of metallurgy as a science and as an engineering profession.

With its usual brevity and wit, Webster's dictionary defines metallurgy as "the science and art of extracting metals from their ores, refining them and preparing them for use." I shall not assume that the words "science" and "art" and "metal" are so well understood as to require no defining but others among our contemporaries are better qualified than either your lecturer or the dictionary to present the broad meanings of these terms. When we say that metallurgy is among the oldest of the arts we are not classing it with painting or sculpture or music but rather with the making of tools or weapons or the building of bridges or chariots or cathedrals. In short we are saying that metallurgy is among the oldest of the engineering professions.

The question "What is metallurgy?" has been one of rather more than ordinary concern to those of us who have the task of developing a curriculum for the education of students in this field. This development has been going on in a number of universities over a period of some years, but there seems to be as yet no unanimity as to what such a curriculum should contain. I believe there is fairly complete agreement that it must be founded upon sound

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basic training in the sciences and that it should contain the elements of an engineering education. The recognition of metallurgy as both science and engineering is fairly widespread among metallurgists. It is not so well understood in other circles.

The terms "metallurgy" and "metallurgical engineering," if each is used in the broadest sense, mean exactly the same thing. I know of two metallurgical departments that have similar curricula, one of which graduates metallurgists, the other metallurgical engineers. For purposes of this discussion, however, I shall use the term "metallurgy" as the broader one to include on the one hand metallurgical engineering and on the other the science of metals.

In connection with our efforts to establish a rational curriculum for students of metallurgy we thought it would be extremely helpful to have before us a concise outline of the entire field. Now it is no small task to prepare such an outline. Metallurgy is a large subject and it overlaps many others so that a clear-cut line of demarcation between it and its neighbors cannot be drawn. The various parts of metallurgy are closely interrelated and cannot be divorced. Nevertheless it is possible to set down in some sort of logical sequence the names of the principal parts of the science and art of extracting metals from their ores, refining them, and preparing them for use.

In presenting the outline I must emphasize that, while the chief impetus for its preparation was pedagogic, it is in no sense an outline of a curriculum. It is not my intention to discuss the pros and cons of the several items which compose the academic bill-of-fare. But this outline which evolved in the course of such discussions may have other than academic uses, and moreover the purpose for which it was developed can best be served by offering wide opportunity for criticism.

There is no universally accepted terminology corresponding to that used in the outline. Other schemes of classification have been employed, for example, "extractive metallurgy" may cover not only the first two engineering divisions and "adaptive metallurgy" the other two, but each term may include also the appropriate parts of metallurgical science. Similarly the term "production metallurgy" could be used to cover some eighty percent of what I have called "metallurgical engineering." Two terms which are conspicuously absent from the outline are "ferrous" and "nonferrous." These terms may be useful industrially but the division of science or engineering along such lines would not be profitable. I have no quarrel with those who would select a different set of words nor indeed with those who would interchange the terms "metallurgy" and "metallurgical engineering."

*A.* Metallurgical Engineering
- *Extractive Metallurgy*
  1. Mineral Dressing
     - *a.* Comminution of ores
     - *b.* Separation of minerals
     - *c.* Leaching
  2. Process Metallurgy
     - *a.* Roasting and sintering
     - *b.* Reduction and smelting
     - *c.* Fuels and combustion
     - *d.* Refractories and furnaces
     - *e.* Heat and fluid flow
     - *f.* Electrometallurgy
     - *g.* Melting, refining and alloying
     - *h.* Casting and solidification
- *Adaptive Metallurgy*
  3. Metal Processing
     - *a.* Hot and cold forming
     - *b.* Foundry practice
     - *c.* Joining
     - *d.* Surface treatment
     - *e.* Powder metallurgy
     - *f.* Heat treatment
  4. Application Metallurgy
     - *a.* Quality control
     - *b.* Selection and specification
     - *c.* Alloy design
     - *d.* Service behavior

*B.* Metallurgical Science
1. *Chemical Metallurgy*
   - *a.* Crystal chemistry and mineralogy
   - *b.* Thermodynamics
   - *c.* Reaction kinetics
   - *d.* Surface chemistry
   - *e.* Electrochemistry
   - *f.* Corrosion
2. *Physical Metallurgy*
   - Metallography
     - *a.* Constitution and phase diagrams
     - *b.* Macro, micro and lattice structure
     - *c.* Grain size and texture
     - *d.* Grain growth and recrystallization
     - *e.* Phase transformations
   - Physics of Metals
     - *f.* Electrical and thermal properties
     - *g.* Atomic bonding and cohesion
     - *h.* Magnetism
     - *i.* Diffusion
     - *j.* Theory of the solid state
   - Mechanical Metallurgy
     - *k.* Elasticity
     - *l.* Anelastic behavior
     - *m.* Plastic flow and work hardening
     - *n.* Rupture and fatigue
     - *o.* Creep
     - *p.* Correlation of structure and mechanical properties

There is of necessity much overlapping in the outline, just as there must be in any attempt to set forth the content of any science. There are interrelationships throughout the outline so numerous that any attempt to show them by subheadings and tie-lines would simply cross-hatch the entire page. The purpose of the outline is not to divide metallurgists into classifications but rather only to simplify the task of examining our metallurgical profession to find out what it contains. To continue this study of the anatomy of metallurgy, let us consider briefly each of the major divisions of the outline.

## Metallurgical Engineering

Metallurgical engineering is the direct descendant of that ancient art first brought to man by the titan demigod Prometheus. He it was who dared oppose the will of newly-crowned Zeus when that cruel monarch planned to sweep mankind off from the world and plant a newer race there. He stole fire from heaven and brought it down to earth for men to use. He taught men the motions of the stars and devised for them numbers and letters. He originated ships and was first to yoke horse to chariot. And, in the words of this first metallurgical engineer:

"For the other helps of man hid underground
The iron and the bronze, silver and gold
Can any dare affirm he found them out
Before me? None, I know! unless he choose
To lie in his vaunt. In one word learn the whole—
That all arts came to mortals from Prometheus."

### MINERAL DRESSING

Metallurgical engineering begins with what is "hid underground," the ore, thus illustrating a constantly recurring phenomenon, that the metallurgist is intimately concerned with nonmetals. Metallurgy must in practice begin with the ore and its first operations are those of mineral dressing. Here it is very closely allied to such fields as solid fuels, ceramics and nonmetallic minerals and like them it is here intimately associated with economic geology and mining. In brief this first segment of metallurgy constitutes also a portion of a broad field which is quite properly termed mineral engineering. Much of the scientific background lies in the fields of crystal chemistry, surface chemistry, mineralogy, hydrodynamics and other branches of knowledge not too familiar to most metallurgists but indicative of the breadth of the field.

The importance of the field is obvious in that almost every ore that comes from the ground requires some processing before smelting or reduction can be undertaken with profit, and it will not be many years before the word "almost" can be omitted. The very question of whether or not a given deposit can be considered an "ore" is conditioned upon the state of the mineral dressing art. The ores from which

the bulk of our copper is now produced were of no value fifty years ago. The development of flotation converted worthless rock into a natural resource. Much of our iron ore of the future must come from rock which today cannot profitably be smelted. We face here one of the great tasks of metallurgical engineering.

### PROCESS METALLURGY

Process metallurgy has a long and honorable history too familiar to most metallurgists to require discussion. This is the very stuff on which the Iron and Steel Division is made. It is the succession of steps or processes by which impure mineral is reduced to metal, refined, alloyed and delivered according to a specification. It is an old art, but with the aid of chemical science it has become a chief part of modern metallurgical engineering. It is closely akin to chemical engineering with which it has many ideas and problems in common. The study of the field in terms of processes rather than by metals here follows the lead of chemical engineering education with its emphasis on the "unit processes."

It is worth noting that process metallurgy is not narrowly concerned only with the metal it produces. It has much to do with nonmetals. Operations begin with minerals and fuels and refractories, and the use of these materials is an essential part of the whole. In nearly every melting process a nonmetallic by-product, a slag, is formed and in many cases this slag is itself a necessary reagent for carrying on the chemical reactions of the process. The chemistry of slags and of slag-metal reactions is extremely important in the control of such processes.

Process metallurgy is concerned also with certain principles which are common to many processes. Among them may be mentioned the flow of gases, combustion, heat flow, material balances and yields, heat balances and thermal efficiency, rates of reactions and the laws of chemical equilibrium. It is the quantitative application of such principles in the smelting and refining of iron and steel which has been the guide to efficient utilization of pressure and of oxygen and which will continue in the future to point the way to new efficiency and economy.

### METAL PROCESSING

The more physical aspects of production metallurgy, the methods of forming into useful shapes, are grouped in the outline under *Metal Processing*. Among these we note the overlapping of metallurgy with recognized trades or professions such as welding, founding, forging, electroplating. These fields are as much parts of metallurgical engineering as are steelmaking or heat treatment, and they deserve as much interest and recognition on the part of the metallurgical profession. For too long a time they have been relegated by metallurgists to rule-of-thumb control. Much can be accomplished here by the application of science and of sound engineering as witness recent advances in welding and the current renaissance in the foundry industry. Here we have seen in recent years the doubling of the strength of gray iron by persuading the graphite to form nodules rather than flakes. We have seen more than the doubling of the dependability of steel castings through control of soundness.

### APPLICATION METALLURGY

The task of putting the right metal in the right spot with full regard for cost and service is an important part of metallurgical engineering. The selection and specification of metals and of their heat treatment is often a task of large proportions involving all the skill and understanding of an experienced metallurgist. The more complex the structure, the more kinds of metals must be taken into consideration; the greater the quantity of production, the more urgent it becomes to select for each part the right alloy, the right quality, for economic manufacture and service. It is in this field particularly that the science of physical metallurgy finds its practical engineering applications, and that metallurgy becomes the servant of all engineering. The metallurgist is constantly working with and for engineers of different backgrounds. He must know their language. He must understand the rudiments of design, of stresses and vibration, of fabrication and inspection and assembly. His success is gauged by his ability to serve his fellowman in adapting the right metal for each use.

Then comes the time when there is no satisfactory metal known for the given task; a new alloy must be designed to fit the job; a research and development program is required. As alloys are obtained which fill the need the requirements go up, still better alloys are required and the process must continue. We are constantly in the midst of such developments, rapid progress being made at present in the development of high-temperature metals. The design of a new alloy for a given purpose may be a very simple or an extremely difficult task, depending upon the availability of basic scientific data needed. The development of our N. E. steels during the war was an example of alloy design on a grand scale, the success of which was assured by adequate knowledge of such controlling factors as steelmaking practice, strength, ductility and hardenability.

## Metallurgical Science

A celebrated nuclear physicist when asked "What is the difference between science and engineering?" replied, "About fifteen years." He implied that it takes engineering about fifteen years to utilize the new things of science.

No one believes that the full engineering use of nuclear fission can be developed in any such short time, but it is true that the nuclear engineering tasks which have already been accomplished (the bomb, and commercial production of radio-isotopes) required much less. In metallurgy the difference in time is likely to vary from plus fifty to minus fifty years. Many a scientific result is left to molder on the shelf for years while others which appear to offer the prospect of economic reward may be converted into engineering application with breath-taking speed. On the other hand engineering developments frequently must be pushed forward without benefit of science. In Professor Howe's view engineering is essentially application, while the function of science is correlation with or without discovery. In 1917 he said: "Pure science in its relation to engineering seems today to be in an intermediate stage of its asymptotic evolution from the state of a follower to that of an absolute dictator." As one who has spent some years in study of the science underlying the art of steelmaking, I feel privileged to say that it is a blessing to humanity that the development of steelmaking practice did not have to await the full understanding of the scientific principles upon which it rests. At the same time I must express the conviction that the science will become more useful to the art as its growth progresses—indeed that it will approach asymptotically,

as Professor Howe has said, although it can never quite reach the state of "an absolute dictator."

## CHEMICAL METALLURGY

The great dependence of process metallurgy upon the basic science of chemistry has been illustrated many times in such activities as the operation of blast furnaces and open hearths and the smelting and refining of all sorts of metals.

Production processes require time; hence, the rates of reactions, the rates of transfer of impurities such as sulphur from metal to slag, the rates of reduction of oxides and other phenomena of chemical kinetics are important to nearly every process. Of perhaps even more basic importance is the question whether or not a proposed reaction will occur at all. We do not make aluminum or zinc in a blast furnace, much as we should like to do so if it were possible. There is also the question of how far a process will go before it reaches equilibrium and finds itself run down like a clock. We do not get all the carbon or sulphur or phosphorus out of a heat of steel for just this reason. Consider the slags which are so important in the conduct of smelting and refining processes. We used to think of them as being made up of various mineral species. Some of us liked to regard them as molecular solutions. Nowadays it seems more probable that they are made up chiefly of ions, electrically charged atoms or groups of atoms, some of the groupings being fairly complex. There is much that is not yet known about slags but a knowledge of their actual structure would undoubtedly aid in understanding their proper control. These are chemical questions and illustrate the dependence of all of our processes upon chemical metallurgy, particularly upon kinetics and thermodynamics.

Certain metals which have only recently come into use and others which, like titanium, are still in the chemical stage give added emphasis to the close relationship between chemistry, process metallurgy and chemical engineering. Every new metal that is brought into use will bring its own problems and its own chemical processes. Many of the metals which are now shrouded in obscurity will inevitably be brought into practical use in the years to come. By the time our metal-hungry civilization has become sufficiently discriminating to demand the highly individualistic properties of some of our rarer metals we will witness the introduction of new and strange methods of production. The metallurgy of gadolinium or dysprosium, for instance, may well involve such processes as solvent extraction, ion exchange, fractional distillation, fluorination, and electrolysis. These are the things which chemistry has in store for metallurgists and they will become as much a part of process metallurgy as the blast furnace or the converter.

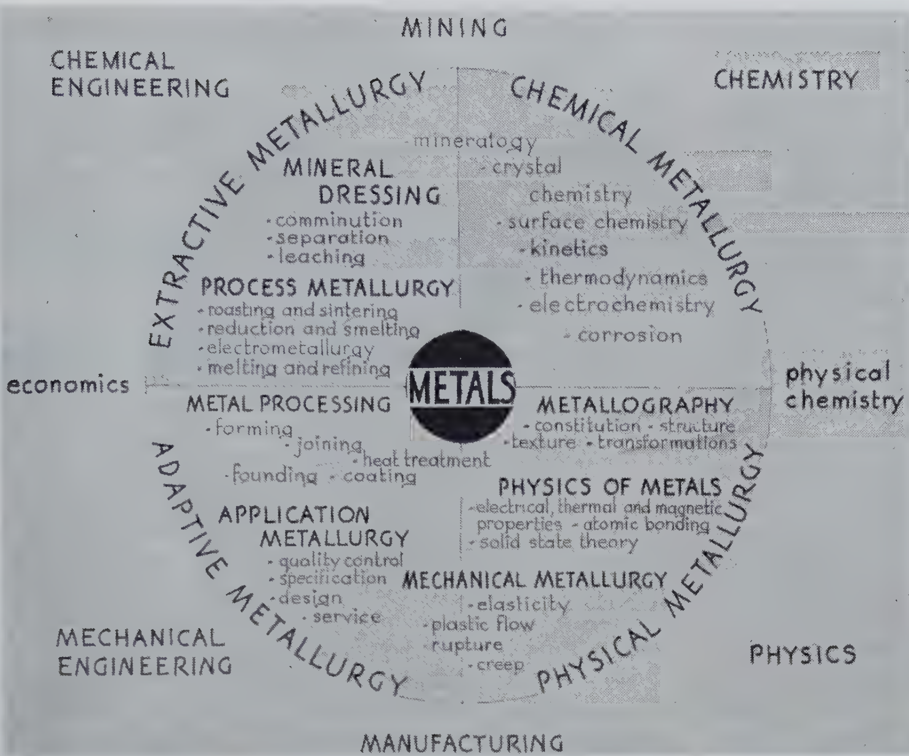
Our interest in chemistry must not end with the production of the metal. Reactions occur within the solid and it is these reactions which provide the basis for heat treatment. Reactions occur also on the surfaces of metals and these provide troubles aplenty for all who are concerned with their service behavior. The control of metal corrosion has become an important engineering activity, but in spite of the great advances that have been made, the world's corrosion bill amounts to several billion dollars every year. The scientific study of corrosion is an important part of chemical metallurgy. To the metallurgist it is obviously dependent upon many factors which we think of as physical metallurgy, since the corrosion behavior of a metal depends not alone upon its chemical nature but upon its structure. But it is highly dependent upon its chemical environment, its electrical contact with other metals and upon that physicochemical super-mystery, passivity.

## PHYSICAL METALLURGY

Physical metallurgy is the science of the metallic state. Offspring of physics and physical chemistry, it is intimately concerned with the structure of metals and alloys and with the phenomena which occur within this structure. The study of metal structures and of the processes which determine them is called *metallography*. It is regrettable that this term has become widely used to connote only the microscopic observation of structure. Its real significance is far wider. In its broad sense it signifies the whole science of metal structure. This includes all knowledge of equilibrium in metallic systems as shown in the many phase diagrams that have been published and the nearly infinite number which remain to be studied. It includes recrystallization and grain growth and precipitation within metallic phases. The whole complex series of changes, by which soft austenite is converted into tough bainite or hard martensite and the latter is tempered to produce structures of desired properties, is a part of this science of metallography. It was in this broad sense that Professor Howe used the word in his "Metallography of Steel and Cast Iron," and I urge that we return to this usage.

Progress in the development of new alloys as well as in understanding and improving the old ones, would be materially accelerated by a more thorough understanding of the nature of the solid state. The forces by which the atoms are bound together in a crystal are far greater than the overall strength of even our best metals. Why cannot we utilize all of this force to produce a steel ten times as strong as our present strongest? Atoms are bound together by electronic forces. Do the electrons spread throughout the structure as a sort of cloud, or do they resonate between several alternative interatomic positions? The answer lies in electrical, magnetic and thermal properties of alloys, and although we do not yet know how to read this answer, we may be confident that it will ultimately play its part in attaining such practical ends as the making of stronger or more ductile steels. The search for a better understanding of the solid state is not something that the metallurgist can leave entirely to the physicist. The two must work together as both kinds of background are needed. The *physics of metals* is an essential part of metallurgy.

Metals are useful primarily because of their mechanical properties, their strength, ductility, elasticity. The study of such phenomena is *mechanical metallurgy*. The metallurgist's approach to studies of elastic and plastic deformation is basically different from that of the mathematical stress analyst. A metal is not a mere three-dimensional continuum possessed of properties expressible in differential equations. It is a complex aggregate of crystals which may differ greatly among themselves and whose properties may change with strain and with time. Why does such an aggregate fail under load, and how? What is the mechanism of the characteristically metallic phenomenon called slip? Why and how are blocks of metal atoms able to glide for great distances over slip planes? Do they really behave like a panful of soap bubbles? By blocking slip planes we can raise the tensile strength. When are we going to learn to do this so effectively as to double the useful strengths of steels?




The Province of Metallurgy and Neighboring Areas.

## Metallurgical Education

One of the principal reasons for asking the question, "What is metallurgy?", has been the need for a system of guide-posts along the road to metallurgical education. With the outline acting as a small-scale map of the province let us have a brief look at the path which a student may follow. One fact stands out clearly—the area is large and the terrain in some parts is rugged. The neophite, planning to spend four years in becoming acquainted with the area, cannot hope to have time to dig deeply into each interesting vein nor to pick all of the daisies that he passes in the field. In planning his tour we must assure that he has an opportunity to see at least a part of each principal area. We must reserve enough time on his itinerary for him to examine in some detail the areas in which he is most interested and we must see that he is equipped with tools for digging in these areas. In addition we must recognize that he is going to spend a part of his time in daisy-picking and other nontechnical activities and we should teach him the difference between wild grape and poison ivy and how to avoid the pitfalls and the rattlesnakes. In introducing him to the province of metallurgy we must see that he learns to mingle not only with his fellow explorers but with the great variety of people whom he will encounter within the field and in adjacent areas.

It is neither feasible nor desirable that all students who spend four years in metallurgical study be subjected to the same instruction. The world has need for many kinds of technically trained people and indeed many kinds of metallurgists. Happily there are enough individualists among metallurgical educators to provide a variety of curricula at the several institutions that offer the subject. In general, departments of metallurgy or of metallurgical engineering have given heed to Professor Howe's warning against Procrusteanism. "You remember Procrustes," he said, "who made his bed fit every traveler by lopping off the tall one's legs and stretching the short ones on a rack. Beware the narrow and cocksure Procrusteans of every walk of life who would have all institutions shaped to fit their own pet ideals regardless of the need of the world of widely different products."

Perhaps it is not generally recognized outside of academic circles that a student of metallurgy devotes only about one-third of his effort during a four-year course to studies of metallurgy. One half of his time is spent on basic science and engineering. This provides a minimum of preparation for entering and exploring the province of metallurgy. Nearly one-fifth is spent on the arts and humanities (daisy-picking and mingling) and this leaves less than one-third for metallurgy. Now it is obviously impossible to cover all that is included or implied in our outline of metallurgy in one-third of a four-year course. A large amount must be omitted and in fact should be. It is quite feasible, however, to teach the fundamental principles underlying most of the subjects listed, provided the student is not overburdened with mere description or with a plethora of specific applications. These rather bare fundamentals plus one or two advanced or specialized studies and a thesis requiring independent laboratory work on a subject, preferably of the student's own choosing, complete the metallurgical part of his schooling.

It is far more important that the student have a real grasp of physical chemistry than that he know the dimensions of the biggest blast furnace or the latest wrinkle in instrumentation. It is far more important that he understand what goes on inside a piece of steel during heat treatment than that he be able to distinguish between

bainite and fine pearlite under the microscope. It is far more important that he be able to *think* than that he know the characteristics of a wide variety of alloys. And it is in the teaching of the fundamentals that the instructor has his best opportunity to help the student learn to think. It seems perfectly clear to me that no part of the fundamentals of metallurgy should be omitted in order to substitute a college professor's idea of how an open hearth furnace ought to operate!

I have been talking of undergraduate instruction; what about postgraduate study? For the great majority of metallurgists this is directly related to a job and is therefore specialized. In many industries definite and well-planned training programs have been set up; these are of very great value to the young metallurgist and to the industry as well. The modern scheme of engineering education is becoming more and more dependent upon such training, and both the universities and the industries are according greater recognition to the responsibilities of the latter in the training of engineers.

Graduate training in the universities generally has one or the other of two objectives: further preparation for a professional career by extension of undergraduate training both in breadth and in depth along some one or two lines of specialization; or preparation for a research career or for leadership in some field in which research plays a dominant part. In a field that is as young and vigorous as metallurgical science, graduate work has much to recommend it. It is, however, by no means to be regarded as a necessary part of a metallurgical education for those whose undergraduate training has been sufficiently basic and sufficiently broad.

## Summary

In summary permit me to repeat that metallurgy is a field of great breadth. Since it is inhabited by metallurgists these must be people of wide vision. I have heard important persons who ought to know better speak of metallurgy as a narrow field of specialization. Nothing could be farther from the truth. It does, of course, contain within its boundaries many fields in which a metallurgist may specialize to his heart's content. But no other branch of engineering can compare with it in breadth if that breadth be gauged by the number of other fields with which it has a common frontier. No other field of applied science draws so heavily upon both of the two basic sciences of physics and chemistry. No field of endeavor exhibits a greater wealth and diversity of achievement. Nowhere can scientists of such a wide variety of interests find a more fruitful or more stimulating field for research.

And now we must attempt to answer the question "What is a metallurgist?" Surely there must be thousands of answers to this question for it is obvious to any observer that no two metallurgists are alike. If we state that "a metallurgist is one whose scientific or professional work is directed toward the production or use or understanding of metals," what more need be said? We have here a definition broad enough to include all of us. However, it is too broad; it needs to be made specific; it requires illustration. Let us add then—"like Henry Marion Howe." And we have no longer a mere definition but an aspiration. For here was a man whose memory still inspires us. Here was a metallurgist whose interests reached into every corner of the province of metallurgy, whose work has influenced every segment of metallurgical science and engineering.

# The Sigma Phase in Ternary Cr-Co-Fe and Cr-Co-Ni Alloys

PAUL A. BECK,* Member and W. D. MANLY,† Junior Member, AIME

In a recent note Sully and Head[1] showed that the Cr-Fe sigma phase is isomorphous with the Cr-Co gamma phase, and that the lattice constants are also nearly identical. In a preliminary investigation of the ternary Cr-Co-Fe system at 800°C at this laboratory the above findings were confirmed, and it was found by microscopic techniques, using various etching reagents, that the two binary phases form an uninterrupted series of solid solutions with each other. These solid solutions occupy a straight narrow band which cuts across the 800°C isothermal section of the ternary system, connecting the two binary phases.

A detailed investigation of the Cr-Co-Ni ternary system at 1200°C disclosed that here, too, the Cr-Co gamma phase extends deep into the ternary system in the form of a long narrow lip. The fact that this sigma type lattice is sustained even when well over half of the Co atoms in it are replaced by Ni atoms, with relatively little change in the Cr content, clearly indicates that Ni itself has a certain tendency to form the sigma phase with chromium. This tendency is hidden in the binary Cr-Ni alloys, where the sigma phase is not known to occur, but it becomes operative in the presence of a sufficient amount of Co. The interpretation of these facts in terms of electron concentrations is rendered difficult by the uncertainty of our present knowledge of the valency electron structure of the transition elements in their alloys. However, Sully and Heal's results and the present work suggest that intermetallic phases with sigma type lattice may occur more frequently in these little investigated alloys than heretofore suspected. In particular, it is expected that a similar phase may exist in the V-Co and perhaps in the V-Ni system, in analogy to the known sigma type phase in the V-Fe system, and that all these sigma type phases may form extensive solid solutions with one another.

[1] A. H. Sully and T. J. Heal: *Research*. March 1948, 1, 288.

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# Distillation of Zinc from Copper Base Alloys and Galvanizers Drosses

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The purpose of this paper is to describe the recent applications and improvements made in the process and equipment for the recovery of metallic zinc from secondary metals by means of high temperature electric resistor furnace distillation.

The process and high temperature furnace, as developed by Revere Copper and Brass Incorporated, Research and Development Department, was described in a previous paper.†

Since the publication of that paper the process and equipment have been licensed to others. Consequently its field of application has been expanded, particularly for the treatment of scrap brass, galvanizers dross and scrap zinc. Other applications are being considered, particularly the melting of metallic titanium and special alloys requiring a controlled atmosphere. Consideration is also being given to modification in design that would allow the melting of copper cathodes for the production of oxygen-free and electrolytic tough pitch copper shapes without the necessity of blowing and poling.

In the design of a furnace for melting copper cathodes it is intended that the fundamental principle of charging the solid material into a large pool of molten metal through a double door charging vestibule as shown in Fig 3 of the previous paper,† would be adhered to and, in addition, either dehydrated and desulphurized producer gas or commercial nitrogen, that is, approximately 96 pct nitrogen, 2 pct hydrogen 2 pct CO, also dehydrated, would be used to provide a protective atmosphere for the resistors and to flush out more soluble gases from the molten copper.

The operation of a small unit producing approximately 1000 lb of copper per hr has shown that the commercial nitrogen will allow the production of tough pitch electrolytic copper when the metal is transferred from the meltdown unit contemplated to a special type induction unit where the oxygen absorption and temperature can be controlled.

Standard practice in treating low grade scrap brass has been to oxidize the zinc by blowing air through the molten metal. This operation results in the recovery of approximately two-thirds or less of the zinc content of the brass in the form of an impure zinc oxide having only a fraction of the value of the zinc in metallic form. The balance of the zinc is lost to slag, fume and drosses. Fig 1 shows the revised flow sheet of the process for the treatment of scrap brass. For this application and as shown on the flow sheet a low frequency induction furnace has been substituted for the Wilkins-Poland type as a melting unit. This type of furnace has been found the most suitable for the purpose as will be shown by the following discussion.

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TP 2577 D. Discussion of this paper (2 copies) may be sent to *Transactions* AIME before July 15, 1949. Manuscript received December 7, 1948; revision received February 4, 1949.

* Administrative Assistant to Vice President in Charge of Research and Development, Revere Copper and Brass Inc., Rome, N. Y.

† F. F. Poland: Distillation of Zinc and Refining of Residual Metals from Copper-base Alloys. TP 2065, *Metals Tech.* (Sept. 1946): *Trans.* AIME (1949) 182 (to be published).

## Scrap Brass

The melting of refinery scrap brass preparatory to distillation presents a melting problem quite different from the usual melting of brass mill scrap for recasting because refinery scrap is a heterogeneous mixture of alloys each having different melting and boiling points, and coated with a variety of corrosion products and foreign materials. In addition, brass and copper plated pieces of sheet iron, stainless steel, ceramic materials, and others are present that do not melt except at temperatures above the boiling point of the liquid bath.

In the previous paper it is noted that difficulty was encountered in the melting of refinery grade scrap brass without excessive loss of zinc by volatilization and that 5 to 10 pct razorite flux was used to alleviate this condition. While this flux was successful in preventing the excessive loss of zinc by volatilization it interposed a low heat conductivity layer between the source of heat and liquid charge and resulted in lowering the melting rate of the furnace. This same problem presents itself in all types of furnaces in which the metal is heated by radiation and conduction from above the charge.

It has been found in melting this type material that the melting rate per hour or per square foot of hearth area

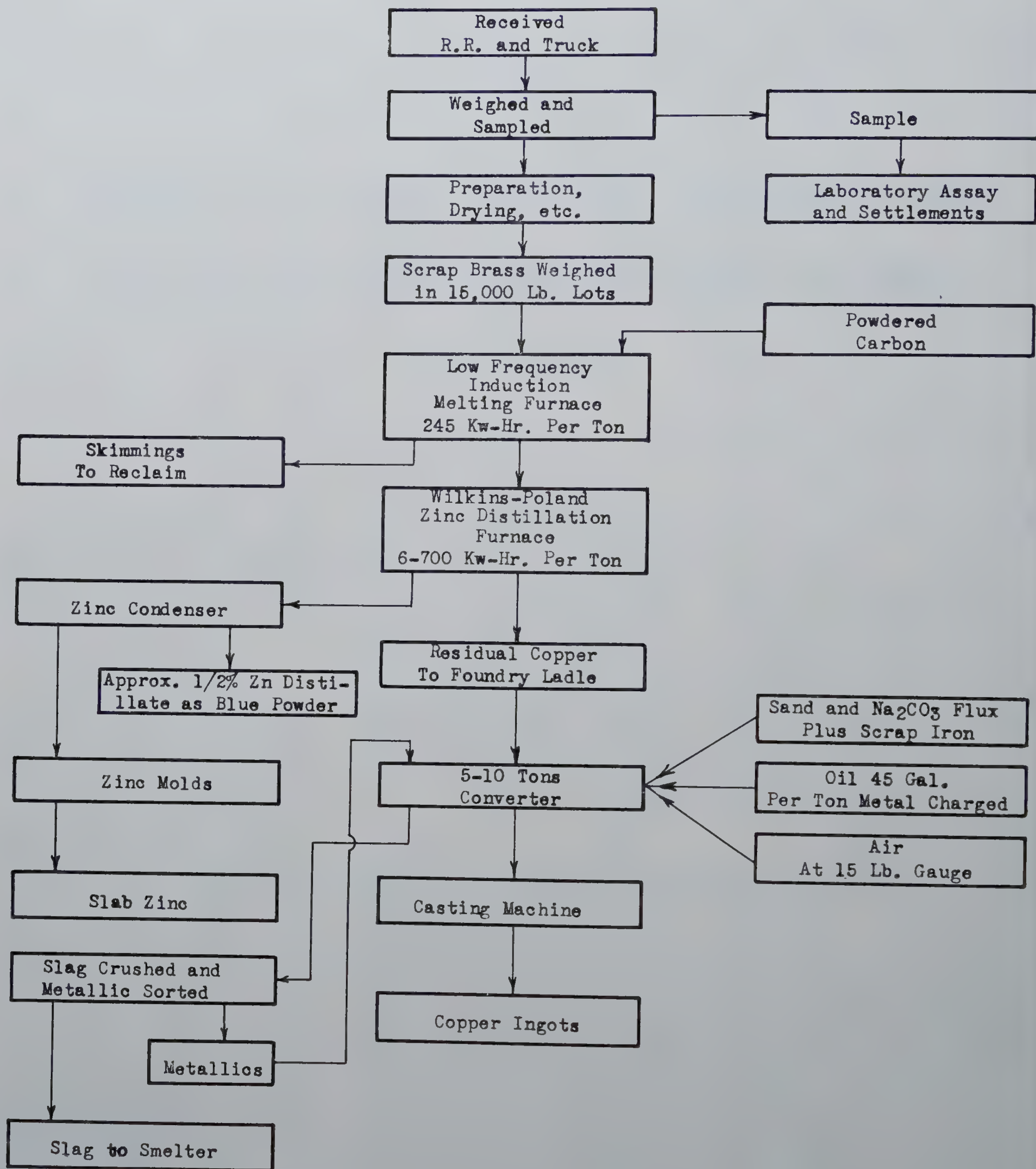


FIG 1—Flowsheet of process for treatment of scrap brass.

for all types of furnaces is considerably less (of the order of 50 pct) than when the same furnace is used for melting scrap alloys or metal of a uniform composition. Allowance for this difference in melting capacity for any given size furnace must be made when designing the melting equipment.

The induction type furnace, because of its generating heat in the charge below the surface, allows the use of a flux or carbon cover so that the benefits of such a cover may be obtained without interference with the heat input to the charge. This type furnace is constructed without any cover or roof which is an advantage in charging bulky material and allows the use of mechanical means for pushing the cold charge into the liquid bath.

The usual secondary winding, that is, heating ducts, in induction furnaces designed for general brass mill casting are not satisfactory for the melting of low grade scrap because this type material does not ordinarily contact the liquid metal enough to absorb the

full rated energy of the furnace, consequently the metal in the secondary boils, pinching off and thereby reducing the power input. A low frequency furnace designed for this particular purpose has larger ducts and more circulation than normally supplied and, in addition, is provided with hydraulic rams to push the cold charge into the liquid bath.

The amount of dross formed when melting this type scrap is ordinarily much greater than that produced when melting scrap brass of uniform composition or even when melting turnings. However, it has been found that a layer of two or more inches of finely divided carbon, or preferably lampblack, on top of the liquid metal, used in conjunction with a hydraulic ram increases the rate of melting to a maximum and reduces the loss of copper and zinc to skims and fume to a minimum.

The finely divided carbon cover on top of the liquid metal produces a very strong reducing atmosphere at the melting zone and experiments have shown that this atmosphere, high in carbon monoxide, will reduce zinc oxide to metal.

Consequently this is an ideal condition and one that is difficult if not impossible to reproduce commercially in any other type of melting furnace.

In melting clean scrap brass, such as mill scrap that contains no ceramic material or other contaminants, there is practically no loss of zinc when melting under the finely divided carbon cover. From these considerations it is believed that the loss of zinc to skims and fume in melting under the conditions described has been reduced to an absolute minimum. The effects on the economics of the operation are shown by the following metallurgical results.

## METALLURGICAL RESULTS

The following are the results obtained from the treatment of a mixture of approximately 1,000 tons of light and heavy miscellaneous yellow brass scrap melted in a low frequency induction furnace equipped with mechanical pushers and using a carbon cover on top of the liquid metal.

The approximate analysis as charged to the induction melting furnace was copper 64.2 pct, zinc 25.5 pct, lead 2.0 pct, tin 1.0 pct, nickel 0.7 pct, aluminum, silicon, manganese 0.3 pct, iron (varies widely) 3.3 pct, infusible material, oil, other combustibles, $H_2O$, etc., 3.0 pct.

There was produced the following, as indicated in Table 1:

### Table 1 . . . Production

| | Pct Gross Scrap |
|---|---|
| Melting furnace skims | 7.7 |
| Zinc slabs | 21.4 |
| Blue powder | .5 |
| Residue copper | 67.9 |
| Volatile and combustible loss | 2.5 |
| | 100.0 |
| **Approximate Zinc Distribution** | **Pct Gross Scrap** |
| Zinc slabs | 21.4 |
| Blue powder | .5 |
| Melting furnace skims at 15 pct zinc | 1.2 |
| 2.7 pct of residue copper | 2.0 |
| Fume | .4 |
| | 25.5 |
| **Zinc Recovery** | **Pct Zinc Contents** |
| Zinc slabs | 83.9 |
| Blue powder | 2.3 |
| Sub Total Recovery | 86.2 |
| Distribution of Zinc Losses | |
| to melting furnace skims | 4.5 |
| to copper shot | 7.8 |
| volatile | 1.5 |
| Sub Total Losses | 13.8 |
| Total | 100.0 |
| | **Pct Copper Contents** |
| Copper produced in residue metal | 96.5 |
| to melting furnace skims | 3.5 |
| Total | 100.0 |

Melting in the reverberatory or converter type furnace results in a zinc loss to slag and fume of between 18 to 30 pct, a fair average being about 23 pct of the total zinc contents. The copper loss to skims is also proportionately greater than in the induction furnace.

The increased amount of zinc lost and the additional amount of by-products to be treated for the recovery of copper results in an estimated difference in returns of approximately \$20.00 per ton of scrap brass treated, in favor of the induction furnace.

The amount of zinc left in the residual copper from the distillation is under the control of the operators and it has been commercially varied from less than 1.5 to 3.5 pct depending upon the planned disposal of the residual metal. The results enumerated above were predicated upon a use where it was desirable to obtain the maximum production and anything under 3 pct zinc in the residual copper was adequate. The temperature of the residual copper as tapped from the distillation furnace was approximately 3200°F. However, these furnaces have been run for considerable periods at much higher temperatures, and in one plant the operating temperature is sufficiently high to reduce the zinc content of the residual metal to less than 1.5 pct. This corresponds to a metal temperature of approximately 3500°F.

There have been no changes made in the condenser or furnace operating temperature from that described in the previous paper. Therefore the copper content of the zinc slabs produced is approximately the same, that is, 0.75 pct. The lead content of the zinc produced was 3+ pct which is normally liquated to Prime Western quality.

In general, it has been found that from 35 to 45 pct of the lead content of the scrap metal is distilled with the zinc. All of the other contaminants have very low vapor pressures at the operating temperatures and consequently copper and lead are the only metals in significant quantity carried to the condenser by the zinc vapor.

## CONVERTING RESIDUAL METALS

Since the publication of the previous paper the plants that have installed this equipment have desired the residual metal for purposes different from those described in that publication. In one plant the residual metal was intended to be made into shot for the manufacture of copper sulphate. In another the residual metal was intended for electrolytic copper refining and in others the residual metal was to be converted for use in the manufacture of copper base ingot alloys. The revised flow sheet (Fig 1) shows the use of a 5 to 10 ton converter instead of the 50 ton previously described. In operating this small converter the residual metal is transferred directly from the distillation furnace and copper oxide added in definite amounts or air blown through the metal to some definite control point, for instance, iron to −0.02 pct, depending upon the end uses as enumerated above. There is nothing particularly new in this general operation. However, it is believed of interest to note that the iron can be reduced to the third decimal point in percentage while 0.75 to 1 pct zinc is still present and that in so doing only about 10 pct of the lead and tin present is removed. After the iron is removed the zinc, tin, lead and nickel are eliminated concurrently but in the order given.

It is common practice in recovering zinc from galvanizers dross to use the retort process. It is well-known by those operating such equipment that it is becoming more and more difficult to obtain labor that is willing to perform the hot, smoky and dirty task connected with this process.

One of the Wilkins-Poland units designed for handling scrap brass was modified to permit a pilot plant operation on the distillation of galvanizers dross, scrap die castings and other scrap zinc and subsequently the engineering company licensed to build these furnaces has designed a unit especially

## Table 2 . . . Comparison of Wilkins-Poland Unit vs. Retort Plant

| | |
|---|---|
| Recovery Retort Plant | |
| Zinc content of galvanizers dross average | 93.5 |
| Zinc slabs produced—pct of gross weight | 86. |
| Losses of Gross Weight | |
| to melting skims | 5. |
| to retort residues—28 pct Zinc | 5–6 |
| to blue powder | 1–2 |
| to fume and other volatile | 1–2 |
| Pct recovery Zinc Slabs $\frac{86}{93.5}$ | 92 |
| Initial cost estimated | $30,000.00 |
| Recovery Wilkins-Poland Unit with Ajax-Tama Melting Furnace Attached | |
| Zinc content of galvanizers dross average | 93.5 |
| Losses | |
| to melting skims | 3 |
| to retort residue—8 pct zinc | 5 |
| to blue powder and volatile | 2 |
| Zinc slabs recovered | 90 |
| Pct recovery $\frac{90}{93.5}$ | 96 |
| Initial cost estimated | $100,000.00 |
| Estimated Operating Cost per Ton in Retort Plant Producing 15 Tons per Day | |
| Labor—5 hr per ton at $1.50 per hr | $ 7.50 |
| Retorts at $200. each | 4.00 |
| 100 gal fuel oil | 10.00 |
| Repairs and replacements retorts | 2.00 |
| | $23.50 |
| 50 pct overhead | 11.75 |
| | $35.25 |
| Amortization of equipment, 10 pct of $30,000. operating 325 days per yr and producing 4875 tons per yr | 0.62 |
| | $35.87 |
| Estimated Operating Cost per Ton in Wilkins-Poland Furnace Producing 15 Tons per Day, 750 KVA Capacity | |
| Labor—2 men each shift—48 labor hr—3.2 at $1.50 | $ 4.80 |
| Power—1150 kw hr per ton at 0.9 cents | 10.35 |
| 150 kw hr per ton melting—1150 | |
| 1000 kw hr per ton distilling— | |
| Repairs at $2.00 per ton | 2.00 |
| | $17.15 |
| 50 pct overhead | 8.57 |
| | $25.72 |
| Amortization of equipment, 10 pct of $100,000 operating 325 days per yr and producing 4875 tons per yr | 2.05 |
| | $27.77 |
| This comparison shows that the savings in operating costs per ton in Wilkins-Poland furnace are | $ 8.10 |
| In addition there is an estimated 4 pct additional recovery which amounts to 2000 lb × 4 pct × 18 cents | 14.40 |
| Total savings to be expected from the use of the Wilkins-Poland furnace | $22.50 per ton dross |

Inasmuch as a production of 4875 tons per yr is involved, a total savings would amount to about $109,000 per yr.

adapted for this purpose. This unit consists of a special type low frequency furnace connected directly to the Wilkins-Poland distillation furnace of standard type.

Table 2 summarizes the results of the pilot plant operation, the estimated cost and the savings to be made. The comparison has been based on the operation of one Wilkins-Poland unit of 750 KVA capacity which is capable of processing 15 tons of dross per day vs. a retort plant equipped with 10 retorts of 4,000 lb capacity each. There will probably be plants in which this size unit would be too large and it is therefore planned to also build these units in sizes about one-half this capacity. This smaller size unit may result in a slightly higher labor cost as compared to the larger unit. However, the savings as compared with the operation of an equivalent retort plant would be in proportion.

It should be noted that the above savings are a comparison in the operating cost between the two types of equipment and that there would be additional savings in freight and treatment charges where the equipment was installed at a galvanizing plant.

In presenting the foregoing figures I am aware that cost figures will vary from plant to plant and from month to month in a given plant. The figures given represent a pilot operation on full scale equipment insofar as the treatment of drosses in the resistor furnace is concerned. They do not, however, comprehend the over-all operation of a large plant.

The cost projected for a retort plant operation represents the best average that could be established on information supplied by operators of plants of this type.

A typical analysis on galvanizers dross is copper 0.01–0.04 pct, lead 0.2–1.0 pct, iron 2.9–3.5 pct, aluminum nil, zinc balance. The slab zinc produced from this type of material will run less than 0.02 pct iron and under Prime Western requirements in lead. The balance is zinc.

The furnace as designed for the distillation of galvanizers dross and other scrap zinc products has a relatively deep hearth so that the iron residue may be accumulated for several days at which time it becomes necessary to stop charging and increase the temperature of the furnace to the melting point of the iron, that is, approximately 2750°F. This allows the residue to be tapped as a liquid containing approximately 8 pct zinc and the balance iron and lead. This residue can be sold to plants operating lead blast furnaces. However, there has been no credit given to the Wilkins-Poland furnace cost estimate for this item.

In the pilot plant operation galvanizers dross, scrap die castings and other scrap zinc, and the like, were redistilled, producing slab zinc running between intermediate and high grade quality. This was accomplished by placing a small condenser in series with a regular condenser and returning an approximately 10 pct fraction condensed in the first condenser to the furnace. The principal reason for doing this was to obtain zinc extremely low in aluminum. The bulk of the material under these conditions was spectroscopically free from this element.

In distilling zinc from galvanizers

dross and other scrap zinc, the furnace can be operated so as to deliver a quite uniform amount of vapor to the condenser. This should prove very desirable in the production of zinc dust which is usually made from this source of zinc.

### FURNACE IMPROVEMENTS

Improvements in construction have been made to the resistor furnace to reduce the heat losses, particularly at the top and side walls above the metal line. This was accomplished by more liberal use of lampblack insulation between the carbon and refractory lining on the side walls and by raising the insulators to a more remote location from the roof plates over the resistors. In consequence of this the weight of the roof and therefore the crane capacity to remove it when necessary was reduced from approximately 15 tons to approximately 5 tons. The power consumption on this later designed furnace is approximately 100 kw hr per ton less than on the original design.

Nonmagnetic steel has been inserted in the area influenced by the magnetic field of the lead-in terminals and the use of noninductive busses combined with the noninductive arrangement of the resistors results in a power factor of between 93 and 96 pct. This high power factor and steady load are of distinct advantage in that the lowest power rates are granted and the initial cost for electrical equipment is at a minimum.

Electric arc furnaces have been and are being used successfully for the melting of electrolytic copper cathodes and a further extension of this application is being made. The difference in the characteristics between the arc furnace and the Wilkins-Poland resistor furnace are such that a considerable reduction in the installed KVA for any given capacity would result in a substantial saving. Increased efficiency due to the reduced radiation losses and extremely low replacement cost of the resistors as compared with arc electrodes makes the resistor furnace more economical than the arc furnace.

Special applications of the Wilkins-Poland furnace are being given consideration where the use of helium, argon, chlorine and nitrogen are to be used as atmospheres. Past experience with nitrogen as an atmosphere has shown that this type furnace can be made practically gas-tight and therefore it is practical to use these expensive gases where necessary.

There have been no changes in the dimensions or design of the condenser. However, one installation is being built in which a small primary condenser will be inserted between the furnace and the regular condenser. The purpose of this is to condense a 10 to 15 pct fraction of the zinc at this point in order to reduce the copper and lead in the approximate 85 pct remainder.

### ECONOMICS

As stated in the previous publication the initial investment for building a plant to recover metallic zinc from scrap brass is appreciably less for this process and equipment than for any previous processes. The operating labor hours and other items as given in the previous publication are still applicable. However, the power required has been reduced approximately 100 kw hr per ton.

## Summary

It has been shown that the high temperature electric resistor furnace distillation of zinc from secondary metals has proven, with further development and use, to be superior in economic and metallurgical results to the older equipment and process.

The economics of melting miscellaneous scrap brass for the recovery of metallic zinc has been discussed and it has been shown that induction electric melting is more economical for this purpose than fuel fired furnaces.

The electric melting of electrolytic copper cathodes has been suggested as an application for the resistor furnace because it is believed to be more economical than the present 250 ton fuel fired reverberatory furnace practice for the production of tough pitch or oxygen free shapes. For this purpose the Wilkins-Poland resistor type furnace would be competitive in installation and operating costs.

Several new installations are in the engineering stage. These plants will be located both in this country and in Europe.

Although it is rather difficult to obtain prompt delivery of the transformers and other electrical equipment necessary for these furnaces at this time, the expansion in their use to date and the degree of interest as shown by inquiries for its application to other fields give every reason to believe that this new metallurgical furnace will find a wide and diversified use in the metallurgical field in the future.

## Acknowledgments

Acknowledgment is made for data obtained from Mr. Fred Rehns, Brooklyne Chemical Co., Baltimore, Md.; Mr. Daniel Ogden, The American Metal Co., New York, N. Y.; Mr. Mario Tama, Ajax Engineering Corporation, Trenton, N. J., and to Mr. R. A. Wilkins for permission to publish the information contained.

# Cadmium Recovery Practice at the Donora Zinc Works

G. T. SMITH* and R. C. MOYER*

## Introduction

Cadmium, along with other impurities such as lead, gallium, germanium and indium, is characteristically found associated with zinc ores, the average ratio of zinc to cadmium being about 200 to 1. The increasing demand for cadmium has led most zinc producers to develop a means for its recovery. The separation and recovery of this byproduct constitutes an important development in the metallurgical field.

Zinc sulphide concentrates, principally from domestic sources, are processed at Donora Zinc Works and they assay approximately 60 pct zinc, 30 pct sulphur, 0.37 pct cadmium, and 0.8 pct lead. Concentrates are roasted to convert zinc sulphide to zinc oxide. Sulphur evolved as sulphur dioxide is used to manufacture 60° Baume sulphuric acid by the lead chamber process. The roasted calcine is sintered to remove the remaining sulphur and volatile impurities. Fume from the sintering machines is collected by Cottrell precipitators and sent to the Cadmium Department for cadmium removal.

The sintered product, a crude zinc oxide, is then mixed with coke and salt and charged into horizontal retorts for reduction to zinc metal. Furnace residues are then passed through a Waelz kiln which recovers practically all of the remaining zinc as an oxide. This oxide is collected by Cottrell precipitators and returned to the sintering plant for further processing.

The following discussion covers operating procedure, and equipment used in the Cadmium Department for the manufacture of cadmium and its byproducts. (See attached Flow Sheet, Fig 1.)

The production of cadmium may be divided into several steps, each of which will be discussed separately. These steps are as follows:

1. Raw Materials—Sinter Plant Cottrell dust, acid sludge and sulphuric acid.
2. Sulphating—Separation of lead.
3. Purification—Separation of impurities other than zinc.
4. Precipitation—Separation of cadmium from zinc.
5. Briquetting—Preparation of sponge for charging to furnace.
6. Smelting—Distillation of cadmium metal.
7. Remelting—Casting into commercial shapes.
8. Recovery of Rare Metals—Separation of germanium, gallium and indium.

## Raw Materials

The raw material, or Sinter Plant Cottrell dust, from which the cadmium is manufactured, is recovered by Cottrell units collecting fume from two Dwight-Lloyd sintering machines. An average analysis of this dust is 36 pct zinc, 1.5 pct sulphur, 17 pct lead, and 5.5 pct cadmium, with associated elements in smaller amounts. A lesser tonnage of material removed from the sintering machine fans, and called fan cleanings, is also treated for cadmium. It is lower grade material and analyzes approximately 41 pct zinc, 1.2 pct sulphur, 14 pct lead, and 4 pct cadmium. Cottrell dust and fan cleanings are delivered to the Cadmium Department by monorail crane in bell-bottomed dump buckets.

Acid sludge and 60° Baume sulphuric acid are received from the Acid Department. The acid sludge is a mixture of lead sulphate, sulphuric acid and zinc sulphate, and is recovered mainly from the floors of the acid chambers or storage tanks. The acid sludge is delivered to the Cadmium Plant in a lead lined bucket. The 60° Baume sulphuric acid is delivered through a lead pipe to a lead lined storage tank.

## Sulphating

Four well ventilated lead lined sulphating tanks, 8½ ft in diam by 12 ft deep, are used. These are steel tanks lined with 20 lb lead on the bottom and 16 lb lead on the sides, equipped with Hastelloy side agitators. 15 hp motors drive 24 in. propellers at 450 rpm. There are water connections to stuffing boxes to keep sludge from entering the bearings. The tanks are covered with removable wooden lids and are connected to marine plywood

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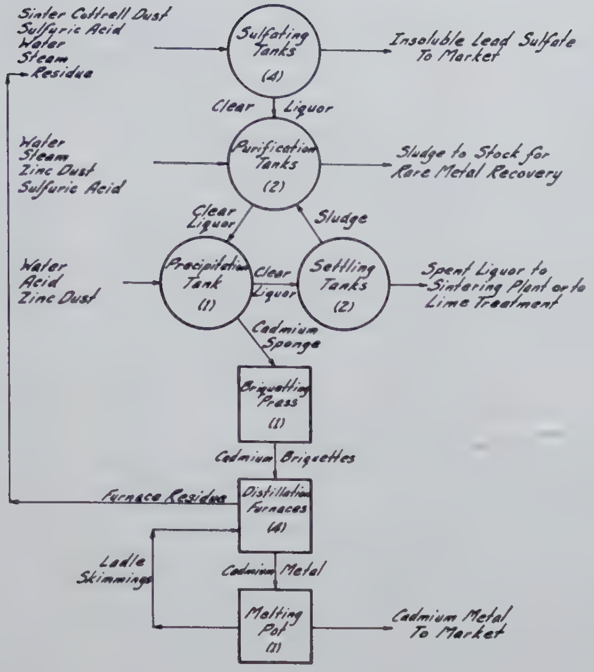


FIG 1—Flow sheet. Fire metallurgy of cadmium.

stacks. The bottoms of the tanks slope, 1 in. per ft, to 4 in. Everdur bronze gate valves. There are air, steam, water, acid and weak liquor connections to each tank.

In the treatment of dust, 3 to 4 ft of water, or weak cadmium wash liquor from a previous batch, is added to the sulphating tank. While this solution is being agitated a bucket of dust is placed on the dumping ring on the tank and the dust added slowly over a period of 15 to 30 min. An average bucket of Cottrell dust weighs 5 or 6 tons.

Acid sludge, when available, is added at this point to supply the necessary sulphuric acid for treatment. Care must be taken that too much sludge, and consequently too much sulphuric acid, is not added. All excess acid must later be neutralized with zinc dust. When no acid sludge is available 60° Baume sulphuric acid, from the Cadmium Plant storage tank, is used. The sulphating tank is then brought to a boil with steam to dissolve soluble material. Usually 4 to 6 hr of boiling and agitation are needed. The acidity is so adjusted that, upon final dilution with water, the solution will show approximately 1 pct acid. After dilution the steam is shut off and the lead sulphate allowed to settle. This settling period may be 6 to 8 hr.

To determine the acidity of the solution, a 10 ml sample of the liquor is titrated with sodium hydroxide using methyl orange as the indicator. It may be necessary to filter the sample before titration.

The purpose of the sulphating treatment is to put cadmium and zinc into solution and to convert lead to lead sulphate. The lead sulphate is practically insoluble and settles to the tank bottom leaving 7 or 8 ft of clear liquor above it. When the sample cup shows that the lead sulphate has settled sufficiently, a suction hose, from a lead LaBour pump, is dropped to within 6 in. of the mud level of the tank and the clear liquor decanted to one of the purification tanks. When the batch of clear liquor has been pumped out, the tank is ready for treatment of more dust. Usually two buckets of Cottrell dust and two tanks of acid sludge may be treated before it is necessary to remove accumulated lead sulphate. If no sludge is available, and sulphuric acid is being used in treatment, three buckets of dust may sometimes be treated before lead sulphate removal.

The above treatment and settling time will vary somewhat with the density, moisture content, chemical characteristics, and physical properties of the dust and sludge.

After the second or third batch of clear liquor has been pumped to the purification tanks, the remaining lead sulphate is given a 1 pct sulphuric acid wash and several water washes. The acid wash is decanted to the purification tanks and treated as regular pregnant cadmium solution. The final washes of 2° Be′ or less are decanted to storage for subsequent use as make-up water in the sulphating tanks. The accumulated lead sulphate is then pumped, as a slurry, to 25 × 50 ft concrete storage bins where it can again settle, and the water can be decanted off as necessary.

The lead sulphate is allowed to accumulate during the winter and in summer weather it is air-dried for shipment to lead smelters. This finished lead sulphate assays approximately 63 pct lead, 1 pct zinc, 0.2 pct cadmium, and may contain small amounts of silver. The use of acid sludge increases the lead content of the lead sulphate.

## Purification

The two purification tanks are 8½ ft in diam and 15 ft deep. They are equipped with agitators, and individually ventilated. Each tank has a hinged cleanout door at the bottom which closes with a wheel clamp. These tanks

are agitated while the clear acid liquor from the sulphating tanks is being pumped into them. Zinc dust, or fine zinc skimmings, is added during agitation in sufficient amount to neutralize the solution. This addition of zinc precipitates part of the cadmium and nearly all impurities such as lead, tin, copper, silver, gallium, indium and germanium. It is very important that these purification tanks be well ventilated because of evolution of nascent hydrogen from the reaction of zinc and sulphuric acid.

The zinc dust or skimmings used as a precipitant is a mixture of metallic zinc and 5–10 pct zinc oxide. Normally 100 to 200 lb of zinc dust are needed to raise the hydrogen ion concentration of the batch to 5.5. The neutral point is checked with methyl red or preferably with Hydrion pH test paper. The tank is then agitated for several hours and allowed to settle. When the solution has settled a suction hose is dropped to within 6 in. of mud level and the clear liquor decanted to the precipitation tank by a LaBour pump. The purification tank is then ready for another batch of liquor from the sulphating tanks.

The liquor pumped to the purification tanks will have a Baume of 20 to 25° and, as stated before, will run about 1 pct acid. Higher acidity may cause a violent evolution of hydrogen and excessive foaming. The Baume must also be kept within reason, since usually the higher Baume solutions settle very slowly. When sufficient sludge has accumulated to prevent the tank from settling properly it is removed as discussed later under "Rare Metal Recovery."

## Precipitation

The precipitation tank is identical with the two that are used for purification. The clear liquor from the purification tanks is pumped into this tank and enough sulphuric acid added to raise the acidity to 0.5 pct. Screened zinc dust or zinc skimmings is then added slowly to the agitated solution to precipitate cadmium sponge. Hydrogen is evolved by the reaction of zinc and sulphuric acid, therefore good ventilation is also necessary here. The solution must be kept acid, since a basic solution will precipitate a sponge which is not suitable for briquetting. A polished strip of metallic zinc is used to determine when all the cadmium has been precipitated. The zinc strip will show no black stain when dipped in liquor from which all cadmium has been removed. The experienced operator can usually determine the end point visually as there is considerable gas evolved. At this point care must be taken to prevent excessive foaming or the tank may overflow.

When the end point is reached, the agitator is turned off and the grey metallic sponge settles quickly to the bottom of the tank. The clear liquor is then decanted to a settling tank. The sponge is not removed after each precipitation but is allowed to accumulate until 2000 to 3000 lb are in the tank. When ready for removal, the sponge is given a 1 pct cold acid wash followed by about six cold water washes. After pumping off the final water wash, the bottom door of the tank is opened and the sponge shoveled into barrels. The barrels of sponge are immediately covered with water to prevent oxidation. If allowed to stand in the air, the sponge becomes very hot and changes to the oxide. The sponge contains 90 to 95 pct cadmium, 1 to 2 pct zinc, 1 to 2 pct lead plus other impurities in small amounts. Most of these impurities are carried from the purification tank to the precipitation tank mechanically since the liquor does not always settle water clear. Also, pockets of gas in the mud on the tank bottom are released as the liquor above is removed and this disturbance in the tank causes some impurities to be carried over.

Following the precipitation tank are two settling tanks 10 ft in diam and 10 ft deep with agitators. The liquor pumped from the precipitation tank usually contains small amounts of cadmium which either are not precipitated or have gone back into solution. A small amount of zinc dust is added to the liquor pumped to the settling tank for removal of this last trace of cadmium and to neutralize any remaining acid. The tank is agitated until a test with tri-methyl-phenyl-ammonium iodide shows no cadmium in solution. The tank is allowed to settle clear.

This clear liquor is then pumped to a storage tank. The sponge which collects in these tanks is removed periodically and returned to the purification tanks, as it is not suitable for briquetting.

Part of this liquor is pumped to the sintering plant and serves as a wetting agent in the charge going to the sintering machines. Any excess wash liquor is treated with lime at the Cadmium Department and the precipitated zinc oxide and calcium sulphate, after being filtered and dried, is sent to the sintering plant.

## Briquetting

The cadmium sponge from the precipitating tank is briquetted in a Watson-Stillman press operated by an Oilgear hydraulic pump. This hydraulic press has a mold 6 in. in diam and 4 in. deep. The sponge is removed from the stock barrels and placed on the press table. To make a briquette, the mold is filled with sponge and pressure is applied. The upper plunger moves down and forces the pressure plate into the mold. Pressure is applied until the water and gas are squeezed out of the sponge and plunger stops moving—a matter of 5 to 10 sec. The upper plunger is then withdrawn and a lower plunger comes up, forcing the briquette from the mold. The briquettes are removed, as made, to a weighing scale, until 500 lb have been made. These 500 lb batches of briquettes are then returned to a barrel and again covered with water.

The finished briquette is 6 in. in diam and from ½ to 1 in. thick. The total pressure applied is approximately 3500 psi. The water and fine particles of sponge, draining away from the press, are returned to the purification tank. This press will make from 1500 to 2000 lb of briquettes per 8 hr shift. The finished briquettes contain about 10 pct water. The briquettes apparently are not affected by being stocked under water, although when held for a considerable time hydrogen gas is slowly evolved.

## Smelting

There are four tilting type furnaces for the distillation of the cadmium briquettes, each of which contains a Lava No. 40 graphite type retort and a cast iron condenser. They are fired by natural gas using a zero gas governor which gives a constant gas and air ratio. The distillation furnace is mounted with short axles on cast iron trunions and may be tilted by a hand wheel gear and pinion from a 30° distillation angle to a horizontal position for cleaning. The furnace is a cylindrical steel shell lined with firebrick and has two tangential burner ports diametrically opposite at the base of the shell to give the gas a swirling motion for uniform heating of the retort. The cast iron condenser is mounted on a four

wheeled iron carriage for convenient removal.

About an hour before charging a retort, 500 lb of briquettes are removed from under water and allowed to drain. The 500 lb charge is then placed in the hot retort. The cast iron condenser is placed in position over the retort and sealed with clay. In approximately one hour, steam from the charge is driven off and the metal begins to distill. The distilled cadmium is tapped, as often as necessary, into iron molds. Ordinarily it takes from 16 to 20 hr for a charge to work off. When the cadmium has distilled, the condenser is removed and the residue and slag scraped from the retort. The retort is then ready for recharging as before. An average 500 lb charge of briquettes will produce about 375 lb of metal and 35 lb of residue plus some condenser cleanings.

Cadmium residue, from the retorts, is crushed and accumulated for retreatment in the sulphating tanks with acid. The acid insoluble material is sent to the Waelz Oxide Plant for removal of residual cadmium. Any slag formed during smelting is also collected and sent to the Waelz Oxide Plant. Condenser cleanings are usually high in metallic cadmium and are recharged into a retort in separate batches. Fumes and dust from the furnaces are collected by hoods and recovered by a cyclone and Dracco dust catcher. This dust and fume are accumulated and acid treated along with residues.

The cadmium metal recovered from briquettes is ordinarily too high in lead for commercial use and must be redistilled. A 1000 lb charge of metal is placed in a relatively new retort and distilled as above, tapping metal from the condenser as often as necessary. A 1000 lb charge will normally produce 975 lb of metal ready for casting into commercial shapes.

## Remelting

Redistilled cadmium is accumulated until a sufficient amount is on hand to fill an order or until it is convenient to recast it into commercial shapes. The cast iron melting pot is gas fired. It is hemispherical in shape, being approximately 4 ft in diam. A considerable amount of skimmings, consisting of a mixture of cadmium oxide and metal, collects on the pot of molten metal and must be skimmed off occasionally. These skimmings are accumulated for recharging into the cadmium furnaces. If the pot of molten metal is held at a high temperature too long, small amounts of zinc present will burn off and the cadmium metal will oxidize excessively. The temperature is kept slightly above the melting point of 320.9°C. The molten cadmium is ladled from the melting pot and cast into commercial shapes. The finished metal will run less than 0.1 pct zinc and less than 0.02 pct lead, plus spectrographic traces of several other elements.

## Rare Metal Recovery

As stated under the heading of "Purification," the impurities removed from the cadmium liquor collect on the tank bottom until this bulk becomes so great that the solution in the tank will not settle properly. At this point, the accumulated sludge must be removed. This sludge contains cadmium, zinc, lead, tin, chromium, copper, germanium, indium, gallium and traces of other elements below zinc in the Electromotive Series. Besides the cadmium and zinc, the only other elements being recovered from this sludge at present are the gallium, indium and germanium.

Previous to its removal, the sludge is given several acid washes to dissolve as much cadmium as possible. Before these washes are allowed to settle, they are made basic with a small amount of zinc dust to reprecipitate any rare metals which may have gone into solution. These decanted washes are treated in the precipitating tank to recover cadmium. The sludge remaining in the purification tank is then given a strong acid treatment to put as much material in solution as possible. After settling, the clear portion of this solution is decanted to the precipitating tank and treated with zinc dust. The precipitated sponge, containing rare metals, is removed, briquetted, and charged as usual into the cadmium furnace. The residue is saved for rare metal recovery. This sponge is occasionally too slimy to briquette and, in this case, is dried on a hot plate prior to treatment for rare metals. Such material may contain 4–7 pct germanium, 5–10 pct indium and less than 1 pct gallium.

The insoluble material remaining in the purification tank, after the strong acid treatment, is mainly lead sulphate and contains approximately 5 pct cadmium, 0.7 pct germanium, and 0.1 pct indium. This residue is pumped as a slurry to a storage bin for future treatment.

A separate set of tanks is used for rare metal recovery. Gallium, indium and germanium are currently being recovered and purified but it is beyond the scope of this paper to go into the methods of concentration and purification.

# Technical Notes

On Feb. 16, 1948, the Board of Directors of AIME authorized the publishing of "Technical Notes" in METALS TECHNOLOGY (as of Jan. 1, 1949, *Transactions Section*, JOURNAL OF METALS · TECHNOLOGY · PRACTICE). The purpose is to provide *prompt* publication of *very short* items of the following general types:

1. Results of short investigations which do not warrant a paper.
2. The conclusions of extensive investigations of insufficient general interest to justify a regular paper.
3. Conclusions arising in the course of an investigation, which, because of interest to others in the field, the author wishes to present prior to completion of the investigation.
4. Pertinent factual comment (not mere argument) on the subject matter of previous "Notes."

Such Notes will be subject to the approval of the Auxiliary and AIME Publications Committees, but can be handled more promptly than regular papers because they need not be referred to readers. The recommended maximum length is 500 words; notes in excess of 1,000 words will not be considered for this type of publication. A graph or photograph may be included as part of the note when particularly illustrative. As with regular papers, contributions to the new section should be submitted to the Secretary of the AIME. Please furnish two copies each complete with illustrations.

# The Statistical Nature of the Endurance Limit

J. T. RANSOM,* Junior Member, and R. F. MEHL,† Member, AIME

For many years the Metals Research Laboratory of Carnegie Institute of Technology has been concerned with the statistical nature of the engineering properties of steel from an experimental viewpoint, particularly those properties representing ductility.[1] In the past three years new work has been directed toward evaluating the statistical nature of the endurance properties. It has been shown that both the fracture curve and the endurance limit in fatigue are markedly statistical in nature.

The *S-N* curve (and the endurance limit) of ferrous materials is often determined with specimens which number as few as ten. The common procedure is to test the first specimen at a stress well above the expected endurance limit. Each succeeding specimen is then tested at a progressively lower stress, until, after five or six tests, a specimen runs ten million or so cycles without failing. Two or three more specimens are then used to find the highest stress at which failure will not occur; the limiting stress determined in this way is called the endurance limit. It has now been found, however, that the variability in the fracture curve and in the endurance limit in heat-treated alloy forging steels is so great that *S-N* curves must be drawn on the basis of distribution curves which can be appraised only by statistical methods.

Two methods have been adopted in this study: (1) straightforward statistical studies of cycles to fracture of a number of specimens at each of a series of stress levels, and (2) a new abbreviated statistical method, known as "staircase testing."[2] The latter consists in testing a series of specimens, one by one, with the test stress for any given specimen automatically

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[1] References are at the end of the note.

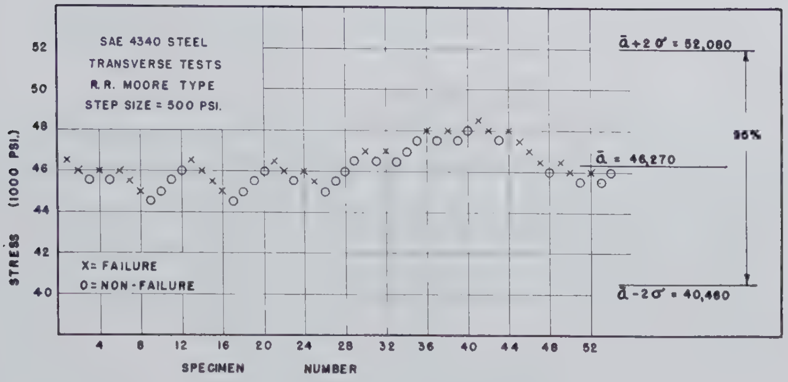


FIG 1—Results on a SAE 4340 steel.

determined by whether the preceding specimen failed or ran out unbroken through ten million cycles. The stress for the first specimen is chosen at a level where 50 pct failures would be expected if a large number of specimens were so tested, that is, at about one-half the tensile strength for steels. If the first specimen fails, the stress for the second specimen is decreased by one step, say 500 psi. If the first specimen "runs out" unbroken, the stress for the second specimen is raised by one step, and so on. The results on a SAE 4340 steel are plotted chronologically as $X$'s (failures) or $O$'s (nonfailures), as in Fig 1. The $X$'s and $O$'s are then used to compute[2] $\bar{a}$, the average endurance limit (the stress at which 50 pct of the specimens would fail and 50 pct run out), and $\sigma$, the standard deviation (if each of a very large number of specimens reveals its own exact endurance limit, the range $\bar{a} \pm 2\sigma$ would include 95 pct of these values). Calculation of the data in Fig 1 results in the prediction that the true scatter range in terms of $\pm 2\sigma$ extends from 40,460 to 52,080 psi.

This result is in conformity with findings of the usual statistical approach; 146 specimens were tested at

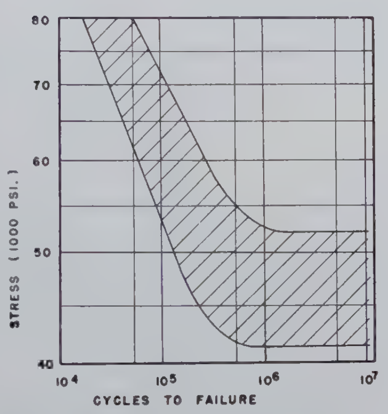


FIG 2—Value of $\pm 2\sigma$ for endurance limit.

stress levels distributed evenly over the 12,000 psi range indicated, and to this were added 64 specimens tested at stresses above the indicated average endurance limit. The value of $\pm 2\sigma$ for the endurance limit as calculated from these data gave 11,250 psi, Fig 2. Similar results were found for other forging steels in both the transverse and the longitudinal directions. It is interesting to note that groups of ten specimens chosen from the 210 samples in a manner to simulate the conventional testing procedure, but otherwise at random, provided eight $S$-$N$ curves with points for each agreeing with the drawn curve as well as on most published curves, but each curve showing wide divergence from one another, giving endurance limits ranging from 50,000 psi to 41,000 psi; such is the way that chance may operate, to the deception of the observer, in a statistical universe.

It is evident that estimates of the true endurance limit and of the fracture curve may be substantially in error when based on the small number of tests commonly employed. It appears that the fatigue properties of such steels can be appraised only on statistical grounds. Moreover, it appears that the endurance limit must be used in design in full recognition of its statistical nature; if design is based upon a stated stress level for the endurance limit, then, on principle, a fixed number of fatigue failures must be expected.

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# Investigation of Temper Brittleness in Low-alloy Steels

S. A. HERRES* and A. R. ELSEA,* Junior Member AIME

Temper brittleness refers to the loss in the notched-bar impact resistance encountered in most medium- or low-alloy steels when they are tempered within the temperature range of 700 to 1100°F or slowly cooled from a higher tempering temperature. Temper brittleness is important because it impairs the service properties of otherwise suitable steels over the range of hardnesses obtained at medium tempering temperatures and because it is impractical to cool pieces of large section rapidly enough from higher tempering temperatures to prevent temper brittleness.

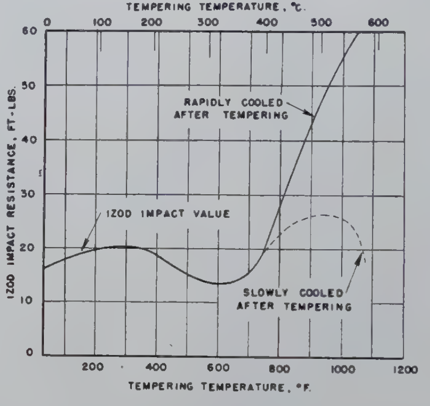


FIG 1—Effect of tempering on impact toughness.[2]

The problem of temper brittleness has always been closely associated with ordnance manufacture because armor plate and gun steels require good shock resistance and are often heat treated in heavy section. However, it is now realized that many brittle failures in structural alloy steel parts are attributable to temper brittleness, and there is little question that it contributes to the low impact resistance of alloy steels used in the hot-rolled or normalized condition which are slowly cooled from the hot-rolling or normalizing temperature.

Recently Hollomon[1] has presented a comprehensive summary of the literature on the subject and an excellent description of the manner in which temper brittleness affects the notched-bar impact resistance and other mechanical properties of steel.

Carpenter and Robertson[2] have given a good analysis of the probable mechanism of temper brittleness, which is similar in many respects to the precipitation-hardening phenomenon. Fig 1 is their diagram illustrating the response to tempering of a susceptible steel. Three changes are recognized as the temperature of tempering a previously quenched steel is raised: (1) precipitation occurs more rapidly and to a greater extent and the notched-bar impact value falls to a minimum; (2) coalescence of the precipitated particles begins to be effective and the impact values for both rapidly cooled and slowly cooled specimens increase; (3) the precipitate goes back into solution at higher tempering temperatures and the impact values of specimens cooled rapidly enough to retain the solution increase, while reprecipitation occurs in slowly cooled specimens and their impact values decrease again. No change must proceed to completion before the following one begins and there is overlapping in temperature ranges.

Although there have been a large number of experimental investigations of temper brittleness, insufficient evidence has been accumulated to permit definite identification of the precipitate which causes temper brittleness nor have the specific effects on it of various alloy elements and impurities in steel been definitely established. This lack of evidence is largely a result of the lack of a suitable measure for temper brittleness.

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[1] References are at the end of the paper.

* Metallurgist, Battelle Memorial Institute.

Temper brittleness is evidenced by an increase in the temperature of brittle failure of notched-bar impact specimens, but most of the data are in the form of an arbitrary susceptibility ratio of the room-temperature impact value for specimens quenched from a high tempering temper to that of similar specimens furnace cooled from the temper. It is obvious that this numerical ratio is dependent upon the type of specimen used and the specific conditions of testing rather than the characteristics of the steel.

In general, manganese, chromium, and nickel alloy steels are most susceptible to temper brittleness and molybdenum has been used to decrease

## Table 1 . . . Chemical Analyses of Experimental Steels

| Type Steel,* Pct | Per Cent | | | | | | |
|---|---|---|---|---|---|---|---|
| | C | Mn | Si | P | S | Al Addition | Others |
| 1.0 Mn | 0.23 | 0.92 | 0.19 | 0.020 | 0.018 | 0.10 | |
| 1.5 Mn | 0.25 | 1.58 | 0.17 | 0.022 | 0.019 | 0.10 | |
| 0.5 C, 1.0 Mn | 0.47 | 1.03 | 0.20 | 0.020 | 0.017 | 0.10 | |
| 3.0 Ni | 0.27 | 0.19 | 0.27 | 0.018 | 0.017 | 0.10 | 2.9 Ni |
| 5.0 Ni | 0.23 | 0.20 | 0.16 | 0.022 | 0.017 | 0.10 | 4.95 Ni |
| 0.75 Cr | 0.26 | 0.21 | 0.26 | 0.018 | 0.016 | 0.10 | 0.72 Cr |
| 1.5 Cr | 0.24 | 0.20 | 0.18 | 0.020 | 0.015 | 0.10 | 1.44 Cr |
| 0.5 Mo | 0.25 | 0.20 | 0.18 | 0.019 | 0.017 | 0.10 | 0.63 Mo |
| 1.0 Mo | | | | | | | 1.0 Mo |
| 2.0 Ni, 0.1 Ti | 0.26 | 0.20 | 0.20 | 0.018 | 0.017 | 0.10 | 2.0 Ni, 0.09 Ti |
| 2.0 Ni, 0.1 V | 0.27 | 0.23 | 0.26 | 0.014 | 0.016 | 0.10 | 2.0 Ni, 0.12 V |
| 3.0 Ni, 0.1 P | 0.25 | 0.20 | 0.16 | 0.110 | 0.016 | 0.10 | 3.0 Ni |
| 1.0 Mn, 0.75 Cr | 0.24 | 1.08 | 0.27 | 0.016 | 0.019 | 0.10 | 0.77 Cr |
| 1.0 Mn, 0.75 Cr, No Al | 0.25 | 1.11 | 0.24 | 0.018 | 0.020 | None | 0.76 Cr |
| 1.0 Mn, 0.75 Cr, 0.20 Mo | 0.23 | 0.99 | 0.20 | 0.016 | 0.019 | 0.10 | 0.78 Cr, 0.20 Mo |
| 1.0 Mn, 0.75 Cr, 0.50 Mo | 0.23 | 1.06 | 0.22 | 0.017 | 0.016 | 0.10 | 0.76 Cr, 0.50 Mo |
| 1.0 Mn, 0.75 Cr, 0.75 Mo | 0.24 | 1.03 | 0.26 | 0.018 | 0.017 | 0.10 | 0.77 Cr, 0.75 Mo |
| 1.0 Mn, 0.75 Cr, 0.06 P | 0.24 | 1.05 | 0.26 | 0.057 | 0.018 | 0.10 | 0.78 Cr |
| 1.0 Mn, 0.75 Cr, 0.005 P | 0.26 | 1.08 | 0.24 | 0.006 | 0.020 | 0.10 | 0.75 Cr |
| 1.5 Mn, 0.005 P | 0.27 | 1.51 | 0.22 | 0.005 | 0.021 | 0.10 | |

* The intended base analysis was 0.25 pct carbon, 0.20 pct manganese, 0.20 pct silicon, 0.02 pct phosphorus, 0.02 pct sulphur (0.1 pct aluminum added).

temper brittleness. The apparent effect of phosphorus in increasing temper brittleness has been attributed by Hollomon[1] to an increase in the temperature of brittle failure of nonembrittled steels of high phosphorus content which in many instances brings the divergence in the impact curves between embrittled and nonembrittled specimens closer to room temperature.

Various investigators have suggested that the temper-brittleness precipitate is a carbide, a nitride, a phosphide, or an oxide. Hollomon[1] states that the rate of diffusion of the responsible element is such that either nitrogen or carbon appears to be involved.

A recent study[3] indicated that neither variations in the nitrogen content of susceptible steels, nor the addition of nitride stabilizing elements such as boron, aluminum, titanium, or zirconium have any appreciable influence on temper brittleness. It is possible to develop a form of temper brittleness in low-carbon Armco ingot iron which appears to be a result of iron carbide precipitate at the grain boundaries. However, when the carbon content is increased to about 0.15 pct and there are a large number of carbide particles throughout the grain, the grain boundary precipitate does not appear and unalloyed carbon steels do not seem to be noticeably temper brittle.

Copper and tin have lower solubility in ferrite at normal temperatures than in ferrite at higher temperatures and when present in sufficient amounts (much larger than normal) may produce a form of temper brittleness. Phosphorus has a solubility of about 1 pct in iron, and would, therefore, not be expected to be a direct cause. Neither oxygen nor sulphur is believed to have the solubility characteristics in ferrite which would lead to temper brittleness, nor do the effects of other elements on temper brittleness fit in with their probable behavior.

This brief discussion indicates the need for further data on the specific influence of various elements on temper brittleness. The remainder of this paper discusses an investigation of the susceptibility to temper brittleness of a series of experimental low-alloy steels.

## Materials and Test Procedures

Twenty experimental steels of the compositions indicated in Table 1 were melted by a standard induction furnace practice in a magnesium oxide crucible. Armco ingot iron was used as a base for all except the last two steels, for which electrolytic iron was used. One-tenth pct each of manganese and silicon was added as ferroalloys with the charge. Carbon and alloy elements were added after melt down. Final deoxidation was made 2 min. before pouring, using ferromanganese and ferrosilicon in all melts and aluminum in all but one. All melts were cast into 50-lb cast-iron ingot molds at a pouring temperature of 2950–3000°F as measured by an optical pyrometer.

The 50-lb ingots were forged to 1¼- × 4-in. billets and then rolled in the longitudinal direction to ½-in. plate at a finish rolling temperature of 1950°F. Impact bars were cut parallel to the rolling direction and ground to ½ in. square before heat treatment. After heat treatment, the bars were finish ground to 0.394 in. square, and a standard Charpy "V" notch was machined on a side perpendicular to the original plate surface. This notch orientation on rolled plate avoids split fractures and meaningless high impact values frequently encountered on specimens from forged bar or plate notched parallel to the rolled surface.

Heat treatments were as indicated in Table 2. The cooling rate on bars furnace cooled from the tempering temperature averaged 30°F per hr over the temperature range of 1100 to 700°F. Impact bars were broken in a standard Amsler impact testing machine with 103 ft lb initial energy in the hammer. Bars tested at subatmospheric temperatures were immersed in a dry ice-acetone bath for at least 15 min. before testing and broken within a few seconds of removal from the bath. Notched-bar impact values are given in Table 2. Rockwell A hardnesses taken on a ground surface of bars representing each heat treatment and Brinell equivalents obtained from the conversion tables supplied by the Wilson Instrument Co. are also given in Table 2.

## Discussion of Results

The impact results given in Table 2 are limited to +75°F and −40°F. A steel which retains a relatively high impact value for the standard Charpy V-notch test at the latter temperature is generally regarded as sufficiently tough for most applications. However, it is not certain that a steel which had

## *Table 2 . . . Results of Notched-bar Impact and Hardness Tests*

| Type Steel,* Pct | Quench | | Tempering Temperature,‡ °F | Hardness | | V-Notch Charpy Impact Ft Lb | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Water Quench | | Furnace Cool | |
| | Temp.,† °F | Media | | Rockwell A | Approx. Bhn | +75°F | −40°F | +75°F | −40°F |
| 1.0 Mn | 1625 | Brine | 1200 | 54–55 | 181 | 103, 103 | 87, 103 | 103, 103 | 93, 97 |
| | 1900 | Brine | 1200 | 54–55 | 181 | | 103, 103 | | 103, 103 |
| 1.5 Mn | 1625 | Brine | 1200 | 56–57 | 197 | 92, 92 | 85, 101 | 82, 82 | 11, 5 |
| 0.5 C, 1.0 Mn | 1625 | Brine | 1200 | 58½–59½ | 217 | 62, 67 | 34, 38 | 62, 65 | 23, 23 |
| | | | 1250 | 57–58½ | 209 | 77, 72 | 33, 36 | 65, 70 | 25, 25 |
| 3.0 Ni | 1625 | Brine | 1200 | 54–55 | 181 | 103, 103 | 103, 103 | 103, 103 | 96, 100 |
| | 1900 | Brine | 1200 | 54–55 | 181 | | 103, 103 | | 103, 102 |
| 5.0 Ni | 1625 | Brine | 1200 | 55–57 | 192 | 86, 90 | 58, 57 | 100, 101 | 88, 103 |
| | | | 1150 | 56½–57 | 199 | | 103, 103 | | 102, 98 |
| 0.75 Cr | 1625 | Brine | 1200 | 58–59 | 214 | 103, 103 | 103, 103 | 103, 103 | 103, 103 |
| | 1900 | Brine | 1200 | 58½–59½ | 217 | | 103, 103 | | 103, 103 |
| 1.5 Cr | 1625 | Brine | 1200 | 59–60 | 223 | 103, 103 | 103, 103 | 103, 103 | 90, 100 |
| | 1750 | Brine | | 58½–59 | 215 | | | | 103, 92 |
| | 1900 | Brine | | 59–60½ | 226 | | 103, 103 | | 49, 15 |
| 0.5 Mo | 1625 | Brine | 1200 | 61–61½ | 236 | 102, 101 | 65, 38 | 103, 103 | 83, 58 |
| | 1900 | Brine | 1200 | 61½–62½ | 241 | | 64, 42 | | 66, 46 |
| 1.0 Mo | 1625 | Brine | 1200 | 62–63 | 248 | 91, 92 | 37, 30 | 81, 81 | 33, 27 |
| | | | 1250 | 61–62 | 238 | | 38, 36 | | 41, 41 |
| 2.0 Ni, 0.1 Ti | 1625 | Brine | 1200 | 55–56 | 181 | 103, 103 | 59, 79 | 103, 103 | 92, 40 |
| | | | 1250 | 53–54½ | 178 | 103, 103 | 94, 91 | 103, 103 | 74, 77 |
| | 1900 | Brine | 1200 | 58–59 | 214 | 97 | 27 | 78 | 18 |
| 2.0 Ni, 0.1 V | 1625 | Brine | 1200 | 62–62½ | 243 | 103, 97 | 49, 44 | 101, 101 | 31, 15 |
| | | | 1250 | 60–61 | 232 | 103, 103 | 71, 54 | 103, 101 | 36, 41 |
| | 1900 | Brine | 1200 | 62–63 | 248 | 100 | 28 | 87 | 23 |
| 3.0 Ni, 0.1 P | 1625 | Brine | 1200 | 56–57 | 197 | 103, 103 | 84, 58 | 57, 60 | 5, 4 |
| | 1900 | Brine | 1200 | 56–56½ | 194 | 103, 103 | 93, 82 | 69 | 30, 27 |
| 1.0 Mn, 0.75 Cr | 1625 | Water | 1200 | 59–60 | 223 | 103, 103 | 97, 96 | 62, 60 | 7, 6 |
| | 1900 | Water | 1200 | 59–60 | 223 | 103 | 100 | 86 | 9 |
| 1.0 Mn, 0.75 Cr, No Al | 1550 | Water | 1200 | 59–60½ | 226 | 93, 93 | 79, 58 | 33, 30 | 3, 4 |
| | 1625 | Water | 1200 | 59½–60 | 226 | 93, 102 | 57, 98 | 7, 8 | 2, 3 |
| | 1900 | Water | 1200 | 59–60½ | 226 | | 41, 52 | | 2, 2 |
| 1.0 Mn, 0.75 Cr, 0.20 Mo | 1625 | Water | 1200 | 60½–61½ | 235 | 103, 103 | 98, 93 | 103, 86 | 86, 81 |
| | 1900 | Water | 1200 | 60–61½ | 233 | | 102, 103 | | 103, 103 |
| 1.0 Mn, 0.75 Cr, 0.50 Mo | 1625 | Water | 1200 | 62–63 | 248 | 87, 88 | 82, 85 | 86, 79 | 88, 87 |
| | 1900 | Water | 1200 | 62½–63 | 251 | 95 | 93 | 95 | 81 |
| 1.0 Mn, 0.75 Cr, 0.75 Mo | 1625 | Water | 1200 | 63–63½ | 256 | 103, 96 | 82, 92 | 72, 69 | 48, 52 |
| 1.0 Mn, 0.75 Cr, 0.06 P | 1625 | Water | 1200 | 60–61 | 232 | 82, 85 | 38, 49 | 2, 2 | 1, 1 |
| 1.0 Mn, 0.75 Cr, 0.005 P | 1625 | Brine | 1200 | 54½–56½ | | 80, 82 | 78, 77 | 80, 80 | 73, 77 |
| 1.5 Mn, 0.005 P | 1625 | Brine | 1200 | 58–60 | | 90, 91 | 94, 95 | 96, 99 | 82, 71 |

* The intended base analysis was 0.25 pct C, 0.20 pct Mn, 0.20 pct Si, 0.02 pct P, and 0.02 pct S.
† Time at temperature = 1 hr.
‡ Time at temperature = 2 hr.

equivalent values for furnace-cooled and water-quenched specimens at −40°F testing temperature would not show temper brittleness at lower testing temperatures.

Some measure of the temper brittleness of the various steels as tested at −40°F may be obtained by subtracting the average value for the furnace-cooled specimens from the average value for the water-quenched specimens. This is believed to give a better picture than the susceptibility ratio which is affected greatly by small differences in the value used for the denominator. The relative temper brittleness of the steels as indicated by this measure is shown in Table 3.

Tables 2 and 3 indicate trends for the influence of various addition elements on temper embrittlement of the base analysis (0.25 pct carbon, 0.20 pct manganese, 0.20 pct silicon, 0.02 pct sulphur, and 0.02 pct phosphorus) as described in the following paragraphs.

Approximately the same increase in hardenability, as calculated by the Grossmann method, should be obtained in the 1.0 pct manganese, 3.0 pct nickel, 0.75 pct chromium, and 0.5 pct molybdenum steels. Microscopic examination indicated that these steels transformed almost completely to martensite during quenching as ½-in.-square bars. All of the steels but the 0.5 pct molybdenum one maintained high impact values at −40°F, and none of them showed temper brittleness on slow cooling from the temper.

### *Table 3 . . . Relative Temper Embrittlement of Experimental Steels at −40°F Testing Temperature*

| Type Steel, Pct | Quenching Temperature (1) | |
|---|---|---|
| | 1625°F | 1900°F |
| 1.0 Mn | 0 | 0 |
| 1.5 Mn | 85 | |
| 0.5 C, 1.0 Mn | 13 9(2) | |
| 3.0 Ni | 5 | 0 |
| 5.0 Ni | 0(3) | |
| 0.75 Cr | 0 | 0 |
| 1.5 Cr | 8 | 71 |
| 0.5 Mo | 0 | 0 |
| 1.0 Mo | 3 0(2) | |
| 2.0 Ni, 0.1 Ti | 0 17(2) | 9 |
| 2.0 Ni, 0.1 V | 23 24(2) | 5 |
| 3.0 Ni, 0.1 P | 67 | 59 |
| 1.0 Mn, 0.75 Cr | 90 | 91 |
| 1.0 Mn, 0.75 Cr, No Al | 75 | 44 |
| 1.0 Mn, 0.75 Cr, 0.20 Mo | 12 | 0 |
| 1.0 Mn, 0.75 Cr, 0.50 Mo | 0 | 12 |
| 1.0 Mn, 0.75 Cr, 0.75 Mo | 37 | |
| 1.0 Mn, 0.75 Cr, 0.06 P | 42 | |
| 1.0 Mn, 0.75 Cr, 0.005 P | 2 | |
| 1.5 Mn, 0.005 P | 18 | |

(1) Tempering temperature 1200°F unless otherwise designated.
(2) 1250°F tempering temperature.
(3) 1150°F tempering temperature.

A further increase in nickel content to 5 pct lowered the critical temperature sufficiently that an intercritical structure with resultant low impact values was obtained for a 1200°F temper, but no temper brittleness was apparent when this steel was properly tempered at 1150°F. An increase of chromium content to 1.5 pct produced slight embrittlement, as did 0.5 pct carbon with 1 pct manganese, and 0.1 pct vanadium or titanium with 2 pct nickel.

Extreme temper embrittlement was produced by increasing the manganese content of the base analysis to 1.5 pct, by the combination of 1 pct manganese and 0.75 pct chromium, or by the addition of phosphorus to a 3 pct nickel steel.

Further experiments with the 1.0 pct manganese, 0.75 pct chromium-type steel were made to investigate the influence of deoxidation practice and molybdenum additions. Comparison of the steels, with and without aluminum addition austenitized at different temperatures to produce marked variation in austenitic grain size, showed no direct influences of these factors on temper embrittlement. Impact values for both water-quenched and furnace-cooled specimens were higher for the

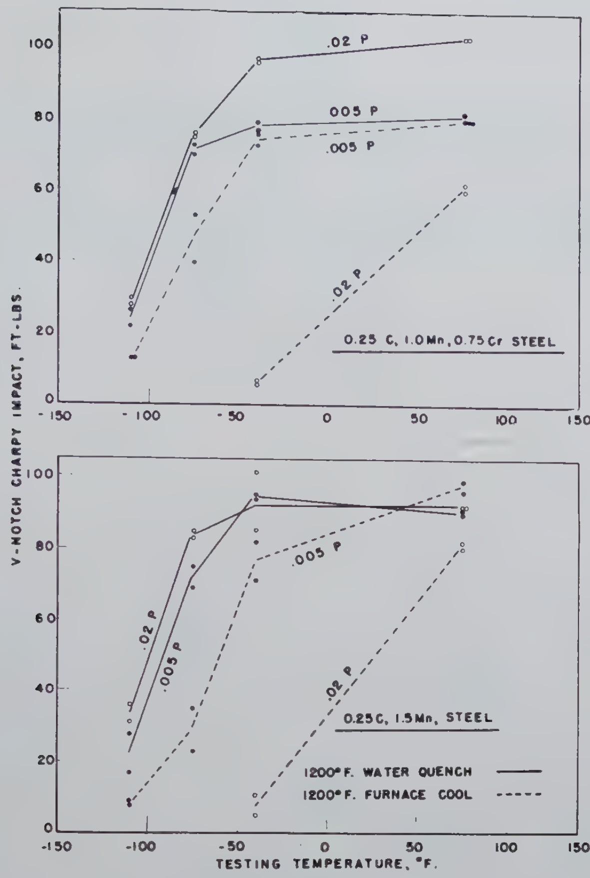


FIG 2—Comparative impact values for 0.02 pct P and 0.005 pct P steels quenched from 1625°F and tempered as indicated.

aluminum-killed steel than for the silicon-killed steel and higher for the silicon-killed steel austenitized at low temperature to give fine grain size.

The influence of molybdenum on temper brittleness is quite complex. An addition of about 0.20 pct molybdenum has a well-known beneficial effect in decreasing the apparent temper embrittlement of susceptible steels. Kishkin[4] reported that additions of molybdenum or columbium, which were effective in preventing temper brittleness of susceptible steels quenched from 1690°F, were ineffective or even increased embrittlement if the steels were quenched from 2280–2370°F. This difference was attributed to solution of the molybdenum or columbium carbides in austenite at the higher, but not at the lower, quenching temperature. Pellini and Queneau[5] reported that temper embrittlement developed in steels with high molybdenum content during extended holding at tempering temperatures as high as 1200°F.

The data of Maurer, Wilms, and Kiessler[6] indicate that, if the molybdenum content is increased beyond a critical amount, the susceptibility to temper brittleness increases again. The results given in Tables 2 and 3 for molybdenum additions to the manganese-chromium steel indicate an optimum molybdenum addition which is less for a higher austenitizing temperature. However, these data on molybdenum additions, as well as the results obtained for 0.5 pct molybdenum, 1.0 pct molybdenum, 2.0 pct nickel-0.1 pct titanium, and 2.0 pct nickel-0.1 pct vanadium steels heat treated at 1625 and 1900°F austenitizing temperatures, and 1200 and 1250°F tempering temperatures, are quite inconclusive as far as establishing any clear picture of the role of these carbide-forming elements on temper embrittlement.

In view of the pronounced effect of an increase in phosphorus content on temper brittleness of the 3 pct nickel steel, two additional melts of the most susceptible steels (1.0 pct manganese, 0.75 pct chromium, and 1.5 pct manganese) were made with an effort to obtain a minimum phosphorus content (0.005 pct phosphorus). A very marked decrease in the temper brittleness of these two steels as indicated by tests at −40°F (Tables 2 and 3) accompanied the decrease in phosphorus from 0.02 to 0.005 pct. In order to determine whether this could be an indirect effect of lowering the transition temperature for brittle failure of both water-quenched and furnace-cooled specimens, additional impact tests were made at −75 and −110°F testing temperatures.

The complete notched-bar impact data for normal and 0.005 pct phosphorus steels are given in Table 4 and plotted in Fig 2. Since lowering the phosphorus content has not improved the impact resistance of the specimens water quenched from the temper, the great improvement in the impact values for furnace-cooled specimens of the 0.005 pct phosphorus steel over those of the 0.02 pct phosphorus steel is attributed to a decrease in the susceptibility to temper embrittlement. As mentioned previously, these steels

**Table 4 . . . Notched-bar Impact Values for Normal and Low-phosphorus Steels**

| Type Steel, Pct | Temper, °F | V-Notch Charpy Impact, Ft Lb | | | |
|---|---|---|---|---|---|
| | | +75°F | −40°F | −75°F | −110°F |
| 1.0 Mn, 0.75 Cr, 0.02 P | 1200 WQ(1) | 103, 103 | 97, 96 | 75, 76 | 27, 22 |
| | 1200 FC(2) | 62, 60 | 7, 6 | | |
| 1.0 Mn, 0.75 Cr, 0.005 P | 1200 WQ | 80, 82 | 79, 77 | 73, 70 | 28, 30 |
| | 1200 FC | 80, 80 | 73, 76 | 53, 40 | 13, 13 |
| 1.5 Mn, 0.02 P | 1200 WQ | 92, 92 | 85, 101 | 83, 85 | 31, 36 |
| | 1200 FC | 82, 82 | 11, 5 | | |
| 1.5 Mn, 0.005 P | 1200 WQ | 90, 91 | 94, 95 | 75, 69 | 28, 17 |
| | 1200 FC | 99, 96 | 82, 71 | 35, 23 | 8, 9 |

(1) Water quenched
(2) Furnace cooled

were made by similar melting procedures and the only known difference, other than phosphorus content, is that electrolytic iron was used for melting stock of the low-phosphorus steel and ingot iron for the normal phosphorus steel.

These results indicate that phosphorus must have a much more important part in temper embrittlement than has been generally supposed. Several explanations are possible, but in view of the lack of fundamental data on the solubility of phosphorus in iron-carbon alloys, its influence on the solubility of carbon, and its reactions with other alloy elements in steel, no theory is advanced at this time.

## Summary

Twenty experimental low-alloy steels were tested for temper embrittlement by comparing notched-bar impact values at +75 and −40°F testing temperature of specimens water quenched and furnace cooled from the tempering temperature.

For these conditions of testing, no embrittlement was apparent for nickel additions up to 5 pct to the base analysis of 0.25 pct carbon, 0.20 pct manganese, 0.20 pct silicon, 0.02 pct phosphorus, and 0.02 pct sulphur. Chromium of 1.5 pct or either 0.1 pct vanadium or 0.1 pct titanium with 2 pct nickel gave slight embrittlement. Manganese of 1.5 pct or 1 pct manganese with 0.75 pct chromium produced extreme embrittlement. Deoxidation practice or grain size did not appear to have any direct influence on embrittlement. A moderate amount of molybdenum decreased embrittlement of the manganese-chromium steel. Increasing the phosphorus content of a 3 pct nickel steel produced temper brittleness, and decreasing the phosphorus content from 0.02 to 0.005 pct greatly decreased the embrittlement of the susceptible 1.5 pct manganese and 1.0 pct manganese-0.75 pct chromium steels.

Impact-resistance, transition-temperature curves for the latter steels indicate a real influence of small differences in phosphorus content on temper brittleness, but in the absence of fundamental data on the behavior of phosphorus in relation to carbon and alloy elements in steel, no theory of the mechanism of this influence is apparent.

## Acknowledgments

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# Oriented Arrangements of Thin Aluminum Films on Ionic Substrates

T. N. RHODIN, JR.*

## Introduction

There can be two types of films on solids, those which are stable in monolayers and those which tend to aggregate into three dimensional structures. A great number of metal films formed by condensation onto a solid base are unstable in the sense that they will aggregate into crystals providing the atoms possess sufficient surface mobility. The crystalline structure of the film is strongly influenced by the base in many systems and, in some cases, a single orientation prevails when the force fields around the atoms in the supporting crystal are sufficiently strong.[1] Relatively little is available in the literature about the nature of these forces and the role they play in promoting a preferred orientation of the atoms arriving at the substrate surface. An understanding of their periodicity and magnitude relative to the surface forces characteristic of the film itself should provide insight into the critical dependence of film orientation on the nature and temperature of the substrate.

In addition, this effect may be very useful in preparing samples for surface studies. The study of the physical and chemical characteristics of pure metal surfaces has been severely handicapped by the presence of strongly adherent foreign films. Furthermore, the randomness of the surface orientation has obscured interpretation of experimental results. Evaporation of metals in high vacuum onto carefully selected substrates under ideal conditions for preferred orientation appears suited to the preparation of flat, oxide-free, oriented films for surface reaction studies. Many factors influence their structure and some understanding of the mechanism of their formation is a necessary prerequisite for obtaining satisfactory surfaces for study. The dominant factors in defining film structure are film thickness and growth rate and the nature, condition, and temperature of the substrate.

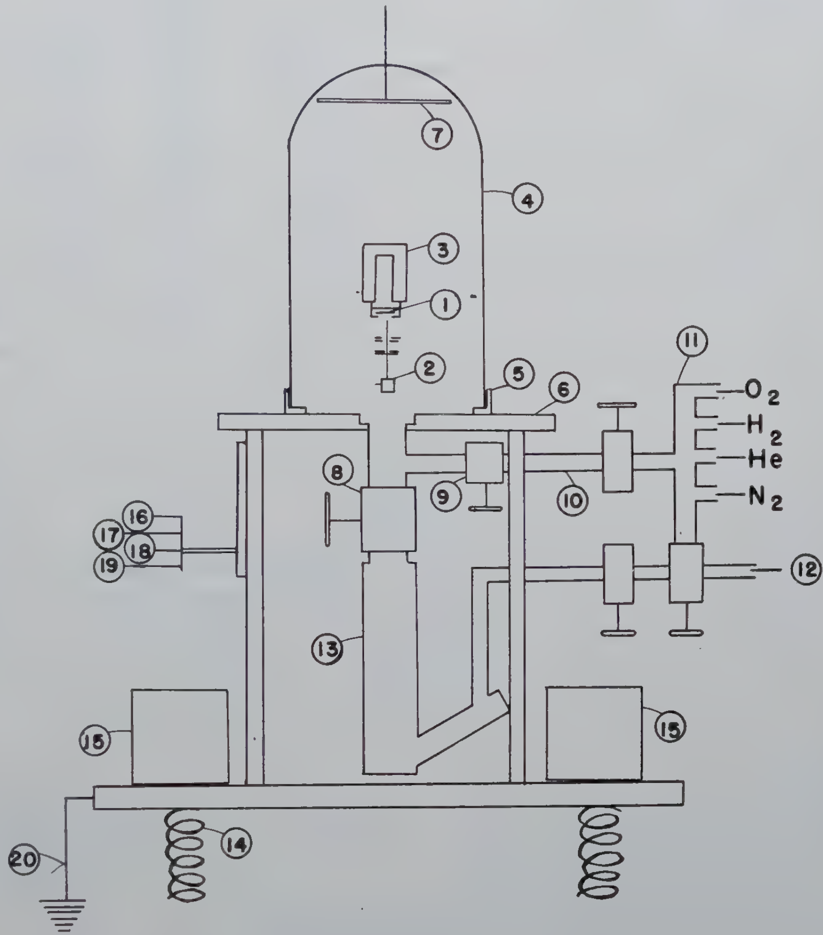


FIG 1—Vacuum evaporator.

1. Substrate
2. Molecular Beam Source
3. Furnace
4. 18 in. Glass Bell Jar
5. Right Angle Neoprene Gasket
6. Polished Steel Plate
7. High Voltage Cathode—5000 V.
8. 4 in. Packless Valve
9. 2 in. Packless valve
10. Manifold
11. Purified Gases
12. Holding Pumps
13. High Capacity Diffusion Pump
14. Shock Mount
15. 200 lb Weights
16. Thermocouple Pressure Gauge
17. Ionization Gauge
18. Temperature Controller
19. Electronic Heater
20. Electrical Ground

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TP 2575 E. Discussion of this paper (2 copies) may be sent to *Transactions* AIME before December 1, 1949. Manuscript received November 19, 1948.

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[1] References are at the end of the paper.

## Procedure

### GENERAL ASSEMBLY

The system was enclosed in an 18 in. bell jar which rested on an L-shaped neoprene gasket on a ground steel plate as indicated in Fig 1. Rapid evacuation of the system to $10^{-6}$ mm mercury was facilitated by a 4 in. manifold, 2 in. packless valve, and an extra large diffusion pump. Suitable arrangement of valves on a secondary manifold readily permitted introduction of purified gases

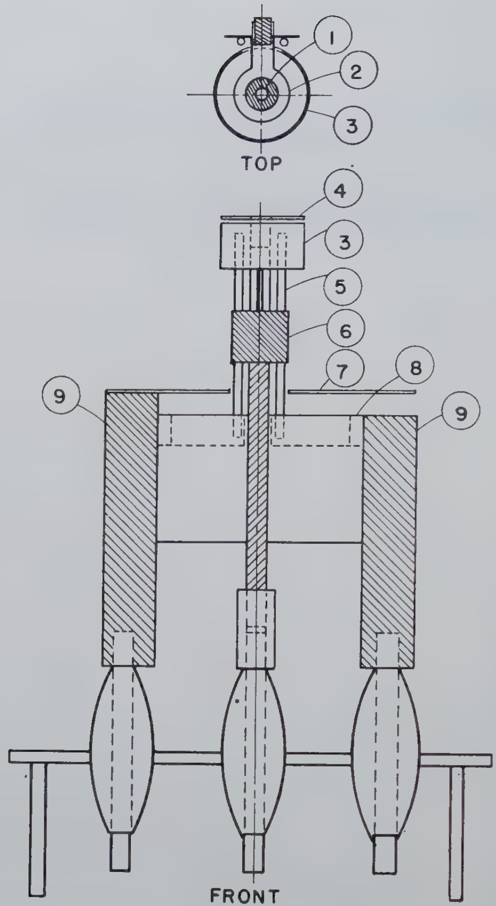



**FIG 2—Electronic heater.**

1. Tantalum Crucible
2. Tungsten Filament
3. Tantalum Shield
4. Tantalum Lid
5. Nickel Leads
6. Crucible Electrode
7. Stainless Steel
8. Mykroy Spacer
9. Filament Electrodes

into the chamber. Outgassing of the entire internal surface in a glow discharge was greatly expedited by a 5000 V copper cathode mounted at the top of the bell jar. The entire frame was carefully shock-mounted to isolate the microbalance from building vibration. The lead-ins for control and power were situated in the steel base. Pressures from 10 to $10^{-6}$ mm mercury could be measured and temperatures of the substrate and crucible could be independently controlled and measured. Atmosphere pressure seated the bell jar hard on the gasket when the latter was evacuated. When it was filled with dry nitrogen at one atmosphere it could be readily elevated out of reach.

## FORMATION OF THE FILM

The film was produced by evaporating high purity (99.99 pct) aluminum from a microcrucible in a good vacuum ($10^{-6}$ mm) and condensing it on an independently heated substrate. With a suitable slit system a uniform, concentrated, direct molecular beam resulted. The arrangement of the source, slits, and substrate is indicated by items 2 and 1 in Fig 1.

The substrate (item 1) was mounted 25 mm above the source in a copper frame which held it in place against an externally heated copper block. In this manner the lower face was exposed to the beam and maintained at the desired temperature by heating from the upper face. The temperature was regulated to one percent by a proportionating potentiometer controller. The substrate consisted of a square plate of an ionic salt approximately 5 mm on the side and 1 mm thick. A freshly cleaved face was exposed just prior to a run. A thermocouple probe in contact with the lower face of the substrate indicated the film temperatures. Two additional platinum probes 2.0 mm apart were in contact with the surface. The appearance of the first few layers of the film was indicated by the sudden decrease in resistance measured between the probes.

The source (item 2) of the beam was a small tantalum crucible located directly below the substrate. The microcrucible held a charge of 100 mgms. The inside diameter of the crucible was 3 mm but the beam was actually emitted through a 0.1 mm orifice in a tantalum cap placed over the top of the microcrucible. The cap prevented splattering and also promoted thermal equilibrium of the atoms before they were emitted. The charge was outgassed by prefusing *in situ* before evaporating during which time the substrate was protected by an externally manipulated shield.

The heating of the crucible was very satisfactorily effected by an arrangement for direct electron heating indicated in Fig 2. The crucible is shown with the lid off as item 1. Electrons emitted from an incandescent 30 mil tungsten filament (item 2) around the crucible are accelerated by a positive

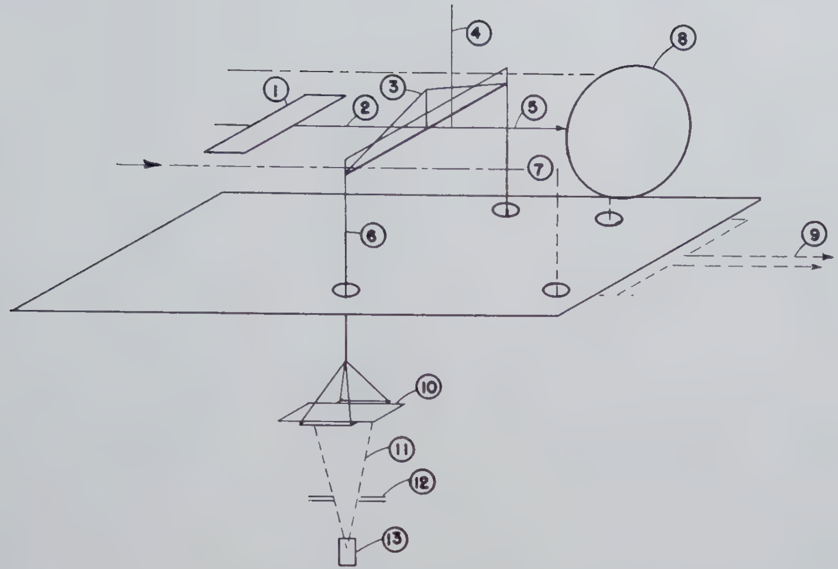


FIG 3—Quartz torsion microbalance.

1. Bow Fibre
2. Static
3. Beam
4. Hang-up
5. Torsion Fibre
6. Hang-down
7. Image of Index
8. Graduated Wheel
9. Single Field Image
10. Substrate
11. Molecular Beam
12. Collimating Slit
13. Source

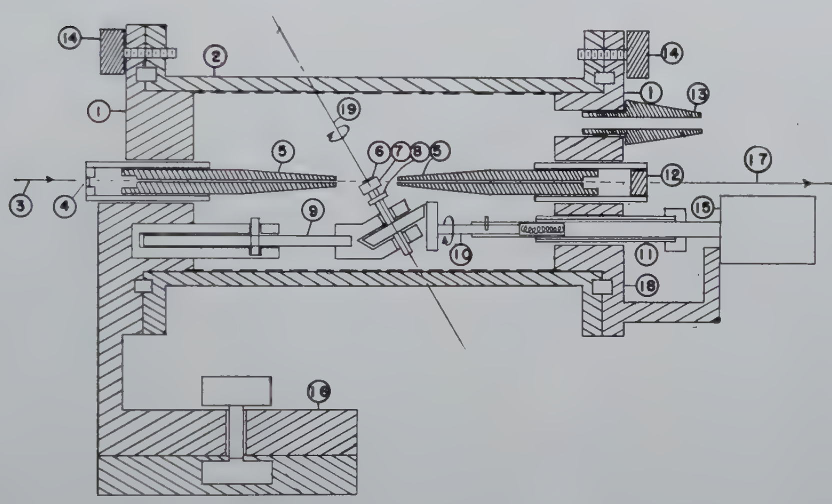


FIG 4—X ray vacuum camera.

1. End Plates
2. Film Case
3. Entrance Beam
4. Beryllium Window
5. Pin Holes
6. Specimen
7. Lucite Spacer
8. Lock-nut
9. Rotor Assembly
10. Drive Wheel Shaft
11. Rotor Vacuum Seal
12. Lead Glass Window
13. Vacuum Outlet
14. Plate Nuts
15. Motor
16. Track Clamp
17. Exit Beam
18. Neoprene Gaskets
19. Axle of Specimen Rotation

potential towards it. A tantalum shield (item 3) around the assembly reduced heat losses and another tantalum lid (item 4) shielded the substrate from direct exposure to the filament. The temperature of the microcrucible could be accurately adjusted and maintained at any temperature up to 1500°C within 2–3 pct by regulating the filament emission and the accelerating potential. This high fidelity temperature control is necessary in the determination of the substrate temperature condensation-pressure relationship for various substrates. The substrate was tied in at the same potential as the crucible to eliminate the possibility that metal ions formed in or around the crucible may be spuriously accelerated towards the substrate.

The critical vapor pressure for condensation on a given substrate at a given temperature could be determined as follows: In this measurement the crucible temperature was slowly increased until the rate of evaporation of the aluminum was just enough to cause condensation on the substrate for a given base temperature. The rapid decrease in the film resistance between the probes was used to indicate the formation of the initial layer. The process was reversible, that is, a small increase in base temperature for a critical pressure caused the film to evaporate. The microcrucible could be readily removed

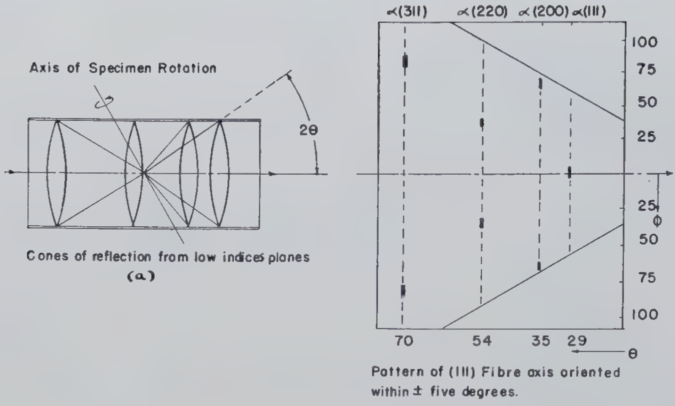



FIG 5—X ray pattern.

from the crucible electrode (item 6) for replacement and the position could be lined up easily by adjusting the eccentric at the base. The crucible temperature was measured by a chromel-alumel thermocouple mounted in the bottom.

### DETERMINATION OF FILM THICKNESS

The condensation rate for a given crucible and substrate temperature was determined by weighing *in situ* a thin glass slide hanging on a quartz fibre over the molecular beam as indicated in Fig 3. A sensitive quartz torsion microbalance facilitated accurate and quick measurements in vacuum. The torsion fibre was rotated by magnetic coupling through the glass wall. The sensitivity of the weighing was $10^{-6}$ gm with a 23 mu. quartz torsion fibre (item 5). The thickness corresponding to weight increments was calculated for a constant area assuming the film to be flat and continuous and the film density to be comparable to the mass density. A microgram corresponded to a hundred angstroms thick layer of aluminum for the film area used. The condensation rates for various substrate and crucible temperatures were calibrated in this manner.

### EXAMINATION OF THE FILM

#### *Metallography*

Upon completion of the run the substrate was cooled *in situ* and removed for examination. Reflectivity of the surface varied from very mirror-like to cloudy as the film thickness and substrate temperature increased. Metallographic examination of the samples was considerably hampered by their fragility. In the cases where it was possible to observe grains without destroying the film the average grain size was 2000 to 5000 Å for a film of the same thickness.

#### *X ray Diffraction*

The structure was determined with X ray diffraction using a surface reflection pin-hole technique in a vacuum camera as indicated in Fig 4. A Picker-Waite diffraction unit was used with a water-cooled chromium target. The exposure time varied from 2 to 15 hr for film thicknesses from 5000 to 500 Å with an accelerating potential of 50 kv and a space current of 10 milliamp. The sample (item 6) was anchored flat on the turntable (item 7) and rotated around an axis (item 19) normal to the surface of the sample. The axis of rotation was inclined away from the incident beam an amount corresponding to the Bragg angle for reflection from the plane of preferred orientation. The camera was particularly designed to suit the geometry and orientation unique to the samples studied. The simplicity of the film patterns indicated in Fig 5a and 5b clearly shows the advantage obtained. Preferred orientation is characterized by segmentation of the lines into local marks as shown by the heavy marks of 5° length on the dashed reflection lines in Fig 5b. The vertical distance from the center line measures the orientation azimuths characteristic of a preferred orientation. The value of the orientation azimuth ($\phi$) can be calculated for any preferred orientation,[1a]

$$\cos \rho = \cos \beta \sin \theta + \sin \beta \cos \theta \cos \phi \quad [1]$$

$\rho$ = angle between oriented plane and reflecting plane.

$\beta$ = angle between normal to oriented plane and incident beam.

$\theta$ = Bragg angle for reflection from reflecting plane.

$\phi$ = orientation azimuth for oriented plane.

The values of $\phi$ calculated for reflection of $K_\alpha$ and $K_\beta$ chromium radiation from the (111), (200), (220) and (311) planes of aluminum for (111), (100) or (110) orientation are listed in Table 1. The kind of orientation can be readily determined from the pattern defined by the characteristic values of $\phi$. A semi-quantitative value for the degree of orientation with a maximum error of 10 pct in this determination can be obtained by measuring the opaqueness of the spot relative to the integrated opaqueness of the whole line with a Leeds and Northrup recording microphotometer. The error is introduced by the assumption that the intensity at any one spot on the film is linearly proportional to the amount of radiation reflected to that point and the dependence is the same for all azimuth angles.

*Table 1 . . . Bragg Angles and Orientation Azimuths Chromium Radiation on Aluminum*

| Radiation Cr$_K$. | Reflecting Plane | Bragg Angles | Orientation Azimuths (111) | (110) | (100) |
|---|---|---|---|---|---|
| $\alpha$ | (111) | 29.5 | 0, 83 | 41, 109 | 64 |
| $\beta$ | (111) | 26.8 | 0, 80 | 39, 105 | 62 |
| $\alpha$ | (200) | 34.7 | 68 | 55, 119 | 0, 119 |
| $\beta$ | (200) | 31.0 | 65 | 53, 111 | 0, 111 |
| $\alpha$ | (220) | 54.4 | 63 | 0, 118 | 82 |
| $\beta$ | (220) | 47.0 | 52 | 0, 94 | 68 |
| $\alpha$ | (311) | 70.0 | 95, – | 104 | 89 |
| $\beta$ | (311) | 59.2 | 58, 142 | 63 | 50 |

## Orientation Results

### GENERAL

A quantitative dependence of degree of preferred orientation on film thickness and substrate temperatures was found over a considerable range of thickness and temperature for eleven aluminum-substrate pairs. It was necessary, however, to make a preliminary evaluation of four other factors sufficiently well so as to minimize their influence. The pertinent results of the preliminary survey are herewith presented in condensed form as a background against which the significance of the quantitative aspects can be considered more intelligently.

#### *Film Growth Rate*

Foremost is the important influence of film growth rate on structure. Since the experimental system was not propitiously suited for studying this aspect it was maintained at a constant value in all experiments. The evaporation

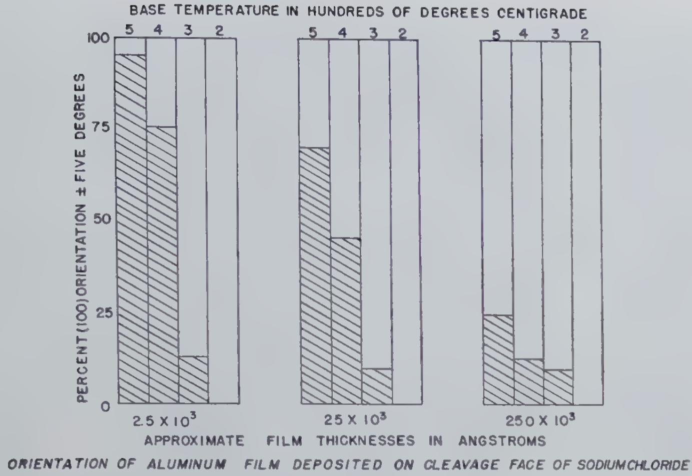



FIG 6—Orientation and base temperature (1).

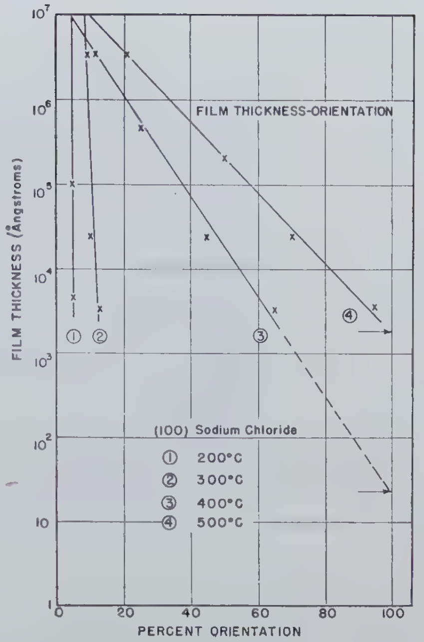



FIG 7—Orientation and film thickness.

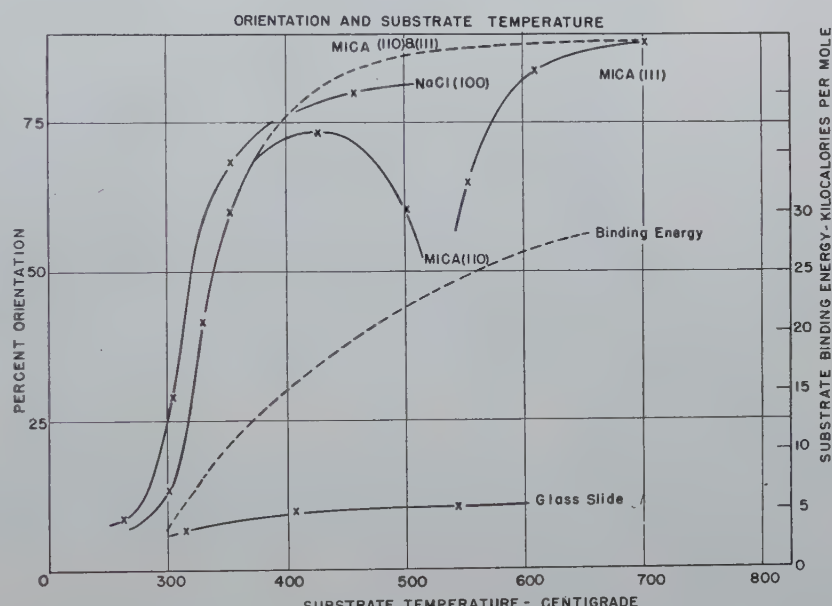



FIG 8—Orientation and base temperature (2).

rate was adjusted for each substrate temperature corresponding to an effective film growth rate of ten to thirty monolayers of aluminum per second. In the case of the binding energy determinations, however, the film growth rate was not controlled since it was desired only to determine the condition for minimum condensation.

### *Heat Treatment*

Heat treating of the substrates with or without adherent metal film caused no striking change in the resulting orientation. The films were therefore usually kept at constant temperature during formation and then permitted to cool by radiation in a vacuum. Annealing a randomly oriented film at elevated temperatures (up to 600°C) in helium resulted only in grain growth. Likewise oriented structures were not markedly altered by annealing under similar conditions. This temperature stability of the structures is in contrast to the temperature sensitive orientations of thinner aluminum films (ca. 400 Å) previously reported.[2]

### *Atmosphere Effects*

The influence of gases present even at $10^{-6}$ mm pressure was also considered. The pressure of purified quantities of helium, oxygen, nitrogen and hydrogen at low pressures ($10^{-4}$ mm) decreased the orientation to a relatively small extent. The effect was not unique to any one gas or substrate and appeared solely to hamper the steady evolution of aluminum vapor. In no case was a gas such as helium observed to improve the film orientation as reported by others for thinner films.[3]

### *Substrate Condition*

The contamination of the substrate surface itself by the gases previously listed was not considered to be critical. Oriented films could be formed on freshly cleaved rock salt which had been preheated in oxygen and hydrogen atmospheres. In all cases, however, the cleanliness of the substrate was a critical requirement and best results were always obtained with freshly cleaved ionic surfaces whose lattices had an arrangement of ions, the geometry and dimensions of which showed a certain correlation to that of aluminum. The limited number of such salts emphasized the preparation of oriented substrates by other means. Even after repeated polishing, etching, and annealing, use of NaCl and LiF surfaces obtained in this manner was only moderately successful. Successful techniques for exposing any desired sub-

strate orientation in a suitably clean and flat condition would be most useful for future studies.

## SPECIFIC FACTORS

### *Film Thickness*

Initial studies made it evident that degree of orientation was very thickness dependent for all film-substrate pairs. This characteristic will be described first since it depended only on temperature and film thickness and was general to all substrates. The percent orientation for films on the (100) face of rock salt for various thicknesses and base temperatures are plotted in Fig 6 as an illustration. An exponential dependence of orientation on film thickness was observed, and the data plotted in Fig 7 indicate a typical case. It is interesting to note that a critical film thickness for perfect orientation at each temperature is suggested by extrapolation of the straight line to small film thicknesses. A striking temperature dependence is also indicated by the distinctly small slope of curve 2 compared to curve 3 in Fig 7. The validity of a strong base temperature-dependence for maximum orientation is also indicated in Fig 8 for a variety of film-substrate pairs. Discussion of the temperature dependence is, however, temporarily postponed until right after the discussion of the thickness effect.

The thickness dependence may mean that the oriented arrangement is constant at all points in the film and merely decreases as the film thickens. It seems more reasonable to assume that the orientation is strongly dependent on the substrate and produces an orientation large at the inner film surface and decreasing towards the outer film surface. The latter possibility is in agreement with the surface reflection characteristics of X rays. In this case a disproportionately large fraction of the radiation producing the pin-hole pattern is reflected from the outer planes of the film. A quantitative illustration of this can be presented by calculating the intensity of radiation reflected from successive layers of metal atoms as follows.[4] The intensity ($I_t$) reflected from a thickness ($t$) relative to the intensity ($I_d$) reflected from an infinitely thick film can be expressed:

$$\frac{I_t}{I_d} = \frac{\int_0^t I_2\,dt}{\int_0^\infty I_2\,dt} \qquad [2]$$

where, $$I_2 = kI_0 e^{-4\left(\frac{\mu}{\rho}\right)\rho\left(\frac{td}{\lambda}\right)} \qquad [3]$$

Neglecting the scattering of the ray after it has emerged from the sample, $I_2$ is the final intensity, $I_1$ the intensity, upon reflection from a diffraction volume element at a depth, ($t$), below the surface, and $I_0$ is the incident intensity before entering the sample. The term $\left(\frac{4td}{\lambda}\right)$ is a linear expression of the total distance traveled in the sample when the ray penetrates a depth, ($t$), and undergoes a Bragg angle reflection. The other symbols are,

$k$ = efficiency constant $\leq$ unity
$I_0$ = initial intensity of incident beam
$\left(\frac{\mu}{\rho}\right)$ = mass absorption coefficient
$\rho$ = film density
$d$ = interplanar distance of oriented planes
$t$ = film thickness penetrated
$\lambda$ = wavelength of X ray radiation.

Values of $\frac{I_t}{I_d}$ for a limiting thickness of $5 \times 10^5$ Å have been calculated from Eq 2 for successive depths of penetration into the sample. The amount of radiation from each layer characterizes the degree of orientation in that layer and the over-all variation of apparent orientation with film thickness indicates the decrease of average orientation with increasing film thickness. The calculations were made for the $K_\alpha$ radiation from a chromium target diffracted by the (100) oriented planes of aluminum. The results in Table 4 are presented: Column 1, depth of penetration (Å); Column 2, thickness penetrated relative to limiting thickness, and Column 3, the corresponding percent intensity for that thickness penetrated over the total radiation recorded on the film.

Although the pin-hole pattern is an integrated effect of orientation through the entire layer, it is obvious that the pattern is a weighted average heavily in favor of the extreme surface. For example, with a chromium target twice as much radiation is reflected from the outer half thickness than from the inner half thickness of an aluminum film 5000 Å thick. Hence, in the film thickness study the orientation of the outer surface was essentially observed. The orientation is greatest in the region nearest to the substrate-film interface.

### *Substrate Temperature*

A base temperature dependence in which orientation of the film increased rapidly at some characteristic temperature for each substrate illustrated in Fig 8 was typical of all substrates. The less the maximum orientation, however, the smaller the dependence on the characteristic temperature. This is illustrated by the contrast in the curves for (100) orientation on rock salt and glass. The temperature dependence may mean that the metal atoms must possess a minimum kinetic energy corresponding to the observed temperature for maximum orientation for them to take up the preferred positions suggested by the substrate. The transition of a (110) orientation of the film on mica at low temperatures to a (111) orientation at higher temperatures indicates that a higher minimum mobility is required for formation of the second configuration. In all cases the rate at which orientation increased with base temperature as well as the maximum value it approached was typical of the substrate. It indicates that production of ordered arrangements is governed not only by the interaction of the substrate and metal but by a relatively slow temperature dependent surface diffusion process as well. Calculation of activation energies for orientation seems premature until the mechanism of arrangement is better defined. The characteristic values of base temperature and maximum observed orientation are plotted in Fig 8 for rock salt, mica, and glass, and listed for eleven substrates in columns 2 and 4 of Table 2.

Experimental data for mica in the temperature region intermediate between the (110) and (111) orientations were inconclusive. It is noteworthy that the most oriented configurations corresponded to the higher temperatures. This characteristic is a general one for all the substrates studied. It is illustrated by the dashed curve in Fig 8 in which the orientation temperature as abcissa is plotted against the substrate binding energy as ordinate on the right. The substrate binding energy, heretofore undefined, is described in a subsequent section and shown to be proportional to the percent of the observed film orientation.

### *Nature of Substrate*

From the facts presented so far it seems clear that the nature and degree of the observed orientation was critically dependent on the substrate. This dependence held in general for all the substrates studied. In every case there was a correlation of some kind between

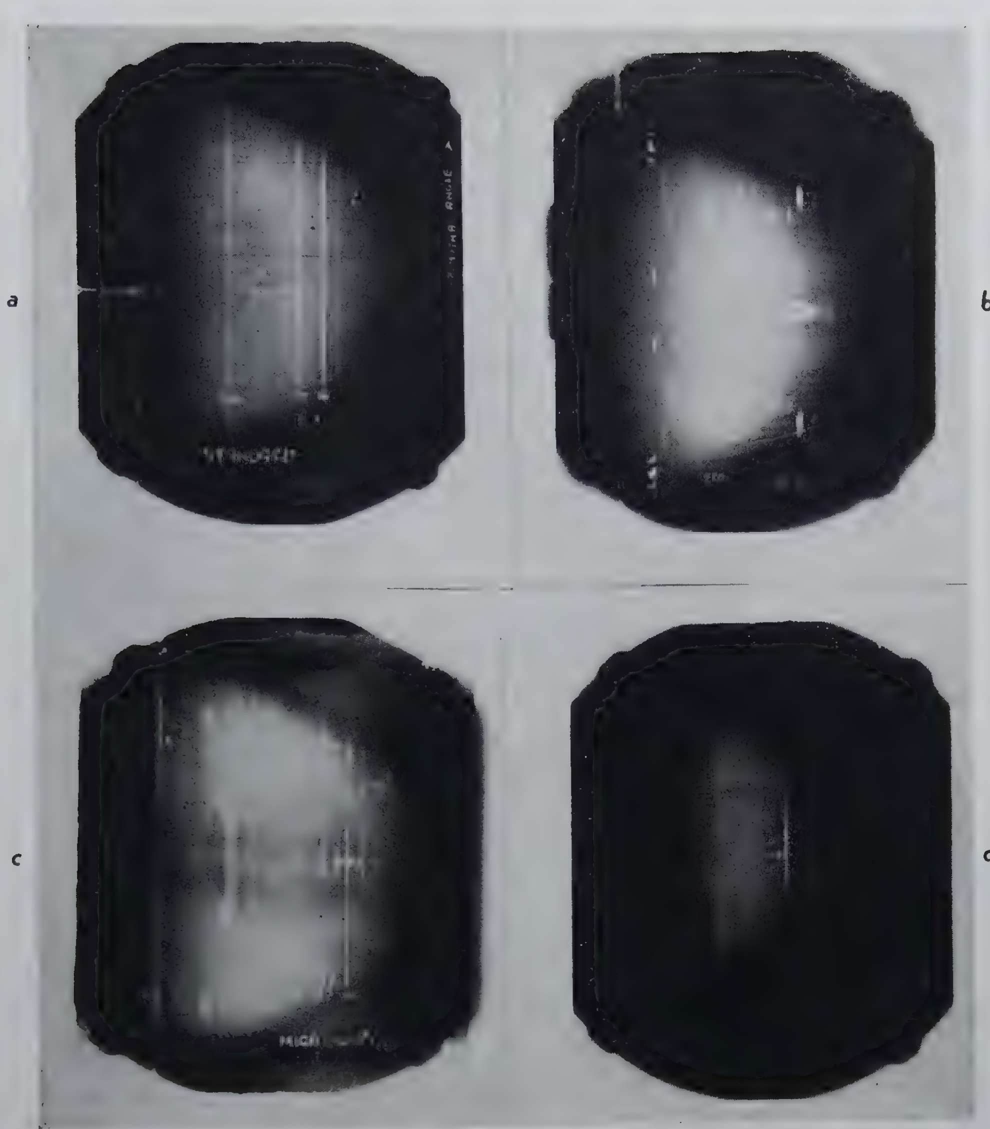



FIG 9a—Aluminum-glass random orientation (10,000 Å).
FIG 9b—Aluminum—(100) sodium chloride 80 pct (100) orientation (1200 Å).
FIG 9c—Aluminum—(111) mica 87 pct (111) orientation (1300 Å).
FIG 9d—Aluminum-glass 10 pct (100) orientation (1000 Å).

the geometry and dimensions of the underlying lattice and that plane of aluminum preferentially oriented parallel to it. For example, the (100) face of aluminum was the only orientation observed on the (100) face of the alkali halide substrates. Similarly the (111) planes of aluminum tended to be preferentially oriented parallel to substrates with hexagonal cleavage or hexagonal-polished faces, providing the base temperature and film thickness were favorable. In other cases (110) orientation was observed to occur on (110) oriented substrates. This is not a general effect, however, since cases occur where substrates stabilize preferred film orientations other than their own, but in most cases that orientation of aluminum occurred for which the geometry and spacing of the metal atoms yielded the best fit on the substrate. The data are summarized in columns 1, 2, 3, 4 of Table 2 in order of decreasing orientation. The direction of orientation in the film listed in the third column is the same as that of the substrate for the first seven items. A small

*Table 2 . . . Structure Characteristics of Thin Aluminum Films*

| Substrate | Temp. Orient. °C | Direct. Orient. | Pct Orient. | Pressure $\times 10^4$ cm Hg | $A$ kc per m | $\Delta$ kc per m | $A - \Delta$ kc per m | $E_c$ kc per m |
|---|---|---|---|---|---|---|---|---|
| mica | 600 | [111] | 87 | 0.007 | 42 | 20 | 22 | 22 |
| mica | 450 | [110] | 75 | 1.52 | 28 | 10 | 18 | 20 |
| NaCl | 350 | [100] | 80 | 0.003 | 31 | 15 | 16 | 18 |
| NaCl | 350 | [110] | 50 | 0.024 | 21 | 10 | 11 | 12 |
| LiF | 400 | [111] | 55 | 0.022 | 33 | 20 | 13 | 10 |
| LiF | 300 | [100] | 50 | 0.012 | 25 | 15 | 10 | 10 |
| $CaCO_3$ | 300 | [111] | 15 | 0.012 | 25 | 20 | 5 | 5 |
| Glass | 400 | [100] | 10 | 6000 | 15 | 15 | 0 | |
| $CaF_2$ | 300 | [111] | 10 | 760 | 20 | 20 | 0 | 2 |
| ZnS | 300 | [111] | 10 | 700 | 21 | 20 | 1 | 4 |
| Sodalite | 300 | [111] | 10 | 700 | 21 | 20 | 1 | 2 |

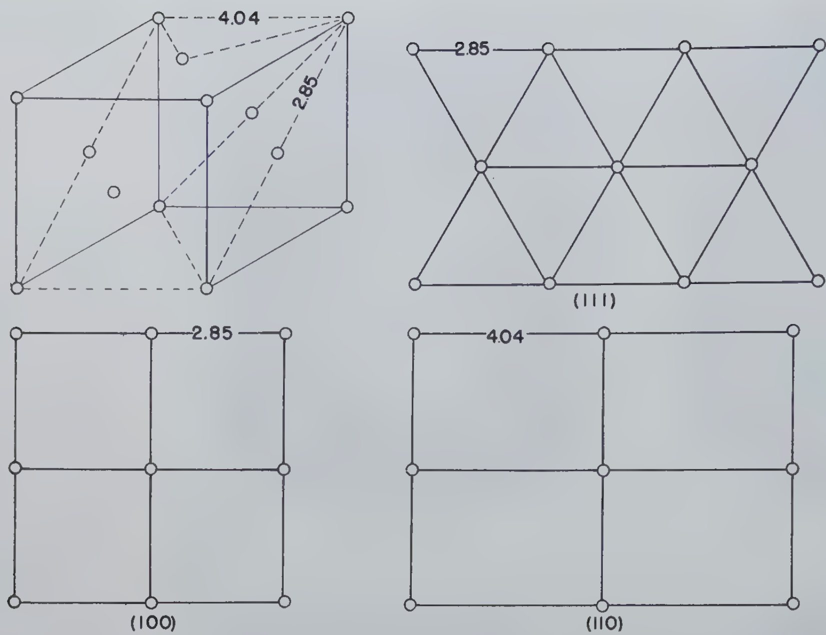
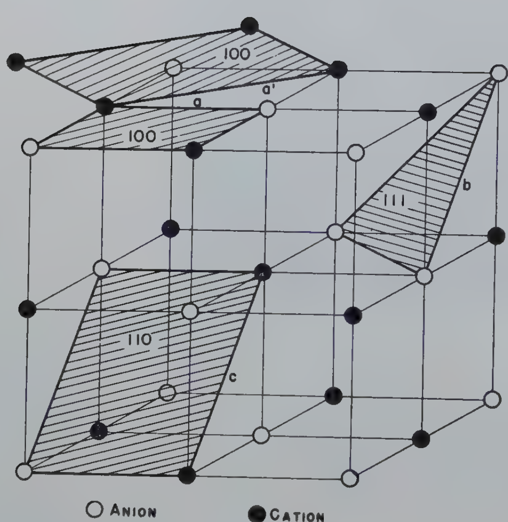



FIG 10—Aluminum unit cell.




| LATTICE PARAMETERS (Å) | Al. | NaCl | LiF |
|---|---|---|---|
| (100) a. | 2.85 | 2.83 | 2.84 |
| (111) b. | 2.85 | 3.98 | 2.84 |
| (110) c. | 4.04 | 3.98 | 4.01 |

FIG 11—Alkali halide unit cell.

orientation was observed on glass which, of course, possesses no definable surface arrangement. The small degree of orientation on fluorite was barely measurable. The (111) orientation on zinc blende and sodalite was also very small. The last two substrates possess cubic lattices with good (110) cleavage faces and are examples of film orientation differing from that of the substrate.

Some typical surface reflection X ray film patterns are illustrated in Fig 4. The interpretation is handicapped by the poor contrast of the aluminum lines, the strong and complex pattern caused by reflection from the substrate, and the poor reproduction, but the over-all pattern analysis is quantitatively unique for each orientation. Continuous reflection from all the low indices reflection planes indicate complete randomness in Fig 9a. The sharply defined orientation of a (100) aluminum film on rock salt is illustrated in Fig 9b. Fig 9c is greatly complicated by the mica pattern but arrows indicate the discrete aluminum reflections corresponding to (111) orientation. A poorly oriented film on glass tending towards (100) orientation is included for comparison (Fig 9d).

## Discussion of Results

### GEOMETRIC CONSIDERATIONS

The good correlation between substrate and film orientation is in accord with the excellent matching between the oriented aluminum plane and the geometry and dimensions of the surface lattice upon which it forms. Similar results have been reported for thinner films.[5] The striking geometric kinship between the three low indices planar arrangements: (100), (110), (111), of aluminum in Fig 10 and the geometry of the corresponding planes in sodium chloride and lithium fluoride in Fig 11 suggests that such correspondence between film and substrate promotes a related orientation in the former. This hypothesis is suggested by the table of lattice distances summarized in Fig 11. They agree within a few percent in each case except for the (111) sodium chloride face, for which the lattice spacing is 40 pct greater than the corresponding spacing in the (111) aluminum plane. It is doubtful whether this correlation is generally essential for substrate-metal interaction but it is significant that no (111) orientation of aluminum was ever observed on a (111) sodium chloride surface. Corresponding orientations were observed in every other case.

Substrates with hexagonal cleavage faces of atomic dimensions corresponding to the (111) face of aluminum yielded (111) oriented aluminum films. The fairly complicated surface structure of mica accommodated (110) arrangement of aluminum as well. The arrangement of the atoms in the hexagonal cleavage faces of mica, calcite and fluorite are drawn to scale in Fig 12. The matching of lattice distances was poorer than for the cubic face cleavage substrates and the observed degree of orientation was also correspondingly poorer with the exception of mica. The (110) cleavage faces of cubic zinc blende and sodalite are not indicated but the matching was relatively poor for both substrates and they were unsatisfactory as (110) directing surfaces.

In all cases studied the nature and degree of the observed film orientation bore a close relationship to the geometry and dimensions of the underlying substrate. It appears that directing forces are geometrically distributed on

the substrate surfaces in close correspondence to the atomic distribution in the substrate plane. An interpretation based on this approach will be discussed in the next section.

## CHARACTERIZATION OF SUBSTRATE

In an effort to characterize the substrates an effect, discovered by Wood[6] and studied by Estermann,[7] was used in a modified form. When a beam of metal vapor is directed at a heated substrate, condensation will occur if the pressure is sufficiently high or the substrate temperature sufficiently low. Whether most of the atoms bounce off the surface losing none or relatively little of their kinetic energy or whether they are accommodated on the surface depends on the relative values of the aforementioned variables plus a third, the attraction of the substrate for the metal atoms. Since the relationship between these factors can be quantitatively expressed, the attraction of the substrate may be determined providing the corresponding pressures and base temperatures can be measured. This pressure-temperature dependence was determined as follows for all the substrate-metal pairs at those substrate temperatures at which maximum orientation was known to occur in each case. The substrate temperature was measured with a thermocouple probe on the surface. The metal pressure was not measured directly but calculated from the crucible temperature using the free energy of vaporization values for aluminum.[8] The minimum vapor pressure was accurately determined for each base temperature at which condensation of the first layers took place. The formation of the first layer was indicated by measuring the sudden drop in film resistance between two probes on the surface. The corresponding values of pressure and base temperature for a group of typical runs are plotted in Fig 13. The pressure-temperature relationship can be expressed,

$$p = a_1 e^{-A/RT} \qquad [4]$$

where,

$p$ = pressure of metal vapor
$a_1$ = constant, insensitive to temperature
$T$ = absolute temperature of the substrate
$A$ = an energy term, characteristic of the film and the substrate.

The values of $a_1$ could be evaluated from the intercept on the pressure axis of the curves plotted in Fig 13. It is insensitive to the nature of the substrate and to the base temperature for the conditions observed. Hence, it was of little use for characterizing the substrates on a relative basis. It, however, includes at least three significant terms describing: (1) geometry of the system; (2) size of the condensing particles; (3) a linear temperature correction. Hence, an interpretation of the mechanism of condensation would eventually require an analysis of $a_1$ into its component terms.

The values of $A$ could be readily interpolated from the slopes of the straight lines plotted in Fig 13. Some typical values are listed there in order of decreasing magnitude. Correspond-

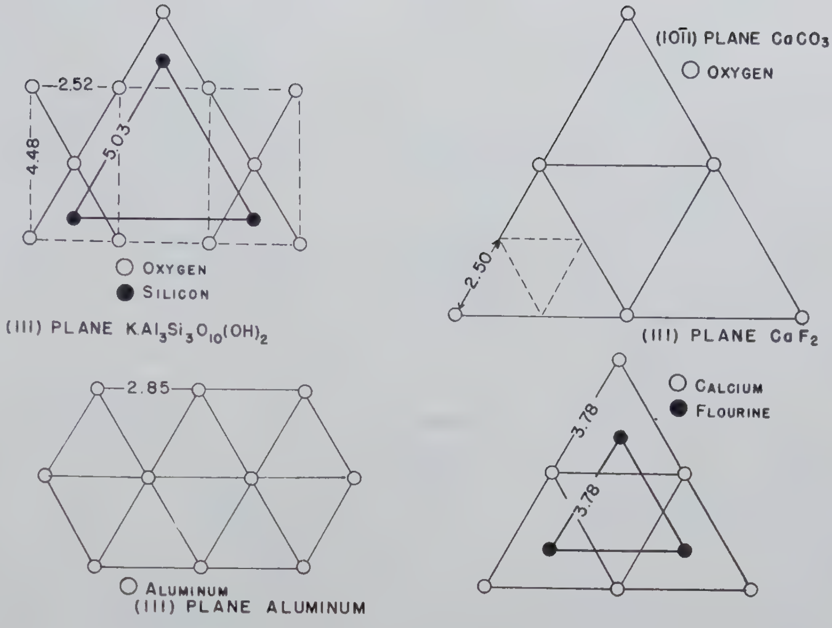



FIG 12—Hexagonal substrates.

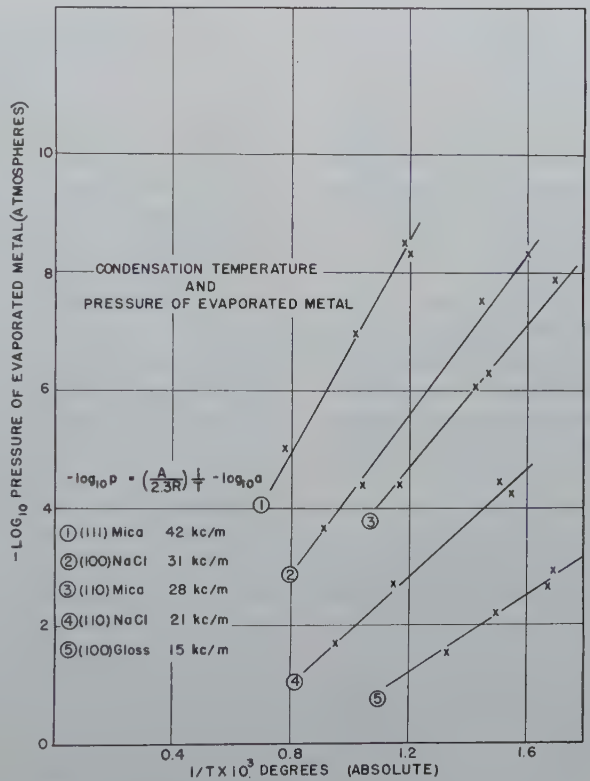



FIG 13—Condensation temperature and pressure.

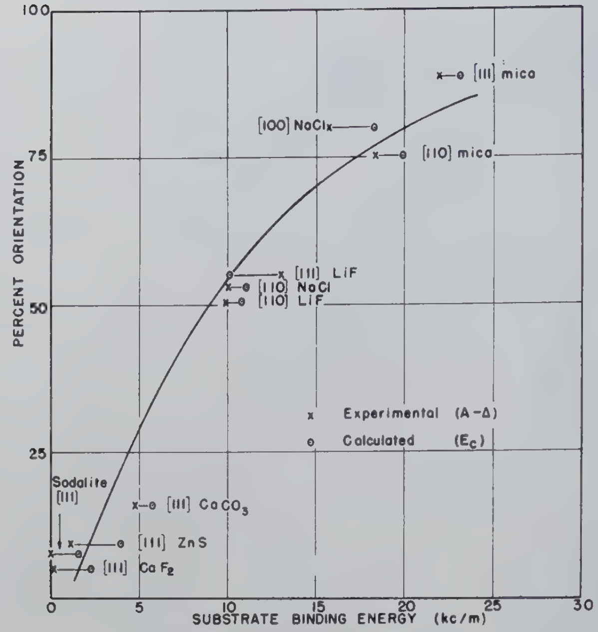



**FIG 14—Orientation and substrate.**

ing values of temperature, pressure, and $A$ are more completely listed in columns 2, 5 and 6 of Table 2.

A definite trend of $A$ in Table 2 from 42 kc per m to 20 kc per m is evident. This trend corresponds to decreasing observed orientation. It is significant that the values of $A$ are smallest for the ionic substrates at the end of the table for which the orientation was poorer. The smaller surface free energy of the (111) arrangement corresponds to the observation that the $A$ values for (111) substrate-film orientations are somewhat greater than those for (110) and (100) orientations for each substrate-metal pair.

An interpretation of $A$ as describing the heat of condensation of the first layer of metal atoms on the substrate is indicated by the temperature dependence relationship established by the straight lines in Fig 13, and by the empirical findings of Wood and Estermann. A theoretical analysis of their work by Semenoff[9] applied to these results indicates that

$$A = E + \Delta \qquad [5]$$

where,

$E$ = the adhesive energy of binding of the metal and substrate

$\Delta$ = the energy of binding of the aluminum atoms in the first layer, that is, the surface energy characteristic of the metal film itself.

If the first term is large the substrate is likely to influence strongly the formation and arrangement of the atoms in the first layer providing the atoms possess sufficient mobility to assume those positions on the surface of lowest potential energy. If it is small, relative to the second term, that is the adhesive forces between metal and substrate are negligible compared to the cohesive binding between metal atoms, the film formation will be relatively independent of the substrate and, should any orientation occur, it will be that arrangement for which the surface free energy is smallest. Formation of an oriented first layer under the first condition would facilitate the occurrence of the same orientation for subsequent layers. The degree of observed orientation should increase with the value of $E$ providing other factors are also favorable, that is, mobile atoms and relatively thin films. Formation of an oriented layer under the second condition may also occur but the degree of orientation will likely be considerably less. It is noteworthy that the values of $A$ varied from 42 kc per m for aluminum on mica to 15 kc per m for aluminum on glass (column 6, Table 2). In the latter case one might consider the interaction between the glass and the metal to exert a relatively small influence on the film structure and the measured heat of condensation to correspond mainly to the cohesive forces in the (100) plane of aluminum. Since there are about one-third the number of bonds in this configuration compared to that of massive aluminum, the surface energy can be roughly approximated to be one-third of the molar heat of vaporization or 22 kc per m. For this crude approximation the order of magnitude agrees with the experimentally determined value measured on an amorphous substance like glass. Neglecting the entropy correction, the substrate binding energy for the other substrate-metal pairs may be similarly approximated by subtracting an energy, $\Delta$, corresponding to the cohesive binding energy of the film, from $A$, the total energy of condensation. In view of the assumptions involved the values obtained are speculative but the resulting values ($E$) listed in column 8 of Table 2 are of the right order of magnitude. These approximations compare favorably with values calculated on the same basis as Van der Waals interaction. The trend of the experimental values of $E$ is in qualitative accord with the trend of observed orientations for each metal-substrate pair. This is indicated by the data on the maximum orientation and the substrate binding energies listed in columns 4 and 8 in Table 2. The correlation is also evident in Fig 14 in which the maximum observed orientation is plotted as ordinate against the substrate binding energy as abcissa. The calculated values, included for comparison, are now discussed.

## VAN DER WAALS INTERACTION

Understanding of the binding between a metal and an ionic surface would provide considerable insight as to the nature of the metal-substrate interaction. A rigorous attempt to define the binding is well beyond the scope

of this paper, but some speculation in this direction seems justified. The characteristics of the binding, namely its relative magnitude and non-specificness, suggest the validity of an approach based on Van der Waals interaction between the first layer of metal and the substrate. An analysis similar to a certain extent to the calculation of heats of adsorption of gases physically adsorbed on ionic surfaces near the boiling point of the gas seems justified. It is obvious that the chief distinguishing characteristic between metal and physically adsorbed gas films, other than the different temperature range in which they form is the marked importance of the cohesive forces in the former case. It is conceivable nevertheless that a strong periodicity in the potential energy surface of the substrate towards the metal atom may be sufficient to start the condensation in a favored direction. The energy of Van der Waals binding of aluminum on each of the substrates was calculated on this basis.

The Van der Waals interaction between non-polar molecules has three important constituent parts: (1) the attraction between fluctuating dipole and induced dipole (dispersion effect), varying inversely as the sixth power of the distance; (2) the attraction between fluctuating quadruple and induced dipole varying inversely as the eighth power of the distance; and (3) the repulsion energy decreasing exponentially with the distance. A fourth constituent part is unique to ionic surfaces: the so-called influence effect. The latter is due to the fact that the charged ions of the substrate induce a dipole moment in the metal atom, which results in an attraction between the ions and the induced dipole. At the equilibrium distances characteristic of the metal films, the first of the four terms is by far the most important. The calculations were made on an approach similar to Orr[10] in which he calculated heats of physical adsorption of argon on potassium chloride.

The dispersion effect was introduced by London[11] in the calculation of heats of adsorption. The dispersion potential $\phi$, between an atom of metal and an ion of the substrate can be written

$$\phi = -\frac{C}{r^6} \qquad [6]$$

where $r$ is the equilibrium distance and $C$, the dispersion constant, is given by

$$C = \frac{3}{2}\alpha\alpha' \frac{JJ'}{J + J'} \qquad [7]$$

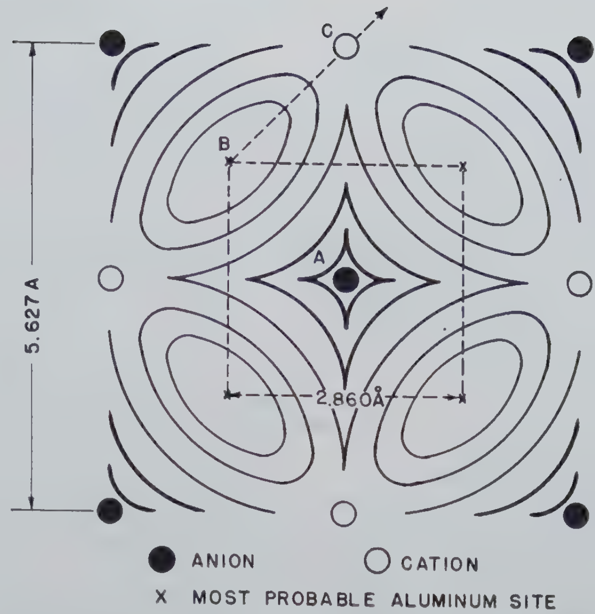



**FIG 15—Potential energy surface aluminum on (100) sodium chloride.**

where

$\alpha$ = polarizability of the metal

$\alpha'$ = polarizability of the ion

$J$ = characteristic energy of the metal

$J'$ = characteristic energy of the ion

The interaction between an atom and the entire surface of the substrate can be very simply calculated if one assumes that the distance between atom and ion is not smaller than the distance between ions. In this case the summation over the ions of the substrate can be replaced by an integration. In the case of alkali halide substrates this approximation will yield values that are too low by 25 to 30 pct. For the mutual dispersion energy of an infinitely large surface and an isolated atom,

$$\phi = -\int \frac{C}{r^6} N dv = -\frac{N\pi C}{6r^3} \qquad [8]$$

where $N$ = number of ions per cc, and $dv$ is the volume element. Substituting Eq 6 for the dispersion constant

$$\phi = -\frac{N\pi}{4}\frac{\alpha\alpha'}{r^3}\frac{JJ'}{J + J'} \qquad [9]$$

An exact evaluation from Eq 8 is not possible because some of the experimental data are missing, particularly the value of $J$ for aluminum. Nevertheless, to show the order of magnitude calculations were made using the first ionization potential. The value of $N$ for the substrates other than the alkali halides was calculated from the density. The distance, $r$, between an ion and an aluminum atom was assumed to be made up of two parts after London.[12]

$$r = \frac{d_1}{2} + \frac{d_2}{2} \qquad [10]$$

For $d_1/2$, half the distance between ions in the substrate was used and for $d_2/2$, half the interplanar distance for that plane of aluminum observed to be

*Table 3 . . . Dispersion Effect. Aluminum on Ionic Substrates*

| Substrate | Plane | Position Center of Face | Ionic Polarizability $\alpha \times 10^{24}$ cm³ | Characteristic Energy $\epsilon_c \times 10^{12}$ ergs per mol | Dispersion Constant $C \times 10^{60}$ ergs cm⁶ | Binding Energy $E \times 10^{-3}$ cal per mol |
|---|---|---|---|---|---|---|
| Sodium Chloride (NaCl) | (100) | two ions | 3.27 | 16.4 | 251 | 18 |
| | (110) | two ions | 3.27 | 16.4 | 251 | 12 |
| | (111) | two ions | 3.27 | 16.4 | 251 | 6 |
| Lithium Fluoride (LiF) | (100) | two ions | 0.93 | 24.3 | 80.8 | 10 |
| | (110) | two ions | 0.93 | 24.3 | 80.8 | 10 |
| | (111) | two ions | 0.93 | 24.3 | 80.8 | 10 |
| Mica ($KAl_3Si_3O_{10}(OH)_2$) | (110) | oxygen ion | 3.88 | 20.5 | 321 | 20 |
| | (111) | oxygen ion | 3.88 | 20.5 | 321 | 22.0 |
| | (111) | silicon ion | 0.17 | 2.0 | 3.6 | 2 |
| Calcite ($CaCO_3$) | (10$\bar{1}$1) | oxygen ion | 3.88 | 20.5 | 321 | 5 |
| Fluorite ($CaF_2$) | (111) | fluorine ion | 1.04 | 19.4 | 84.4 | 2 |
| Zinc Blende (ZnS) | (110) | sulphur ion | 10.2 | 17.5 | 544 | 4 |
| Sodalite ($Na_4Al_3Si_3O_{12}Cl$) | (110) | oxygen ion | 3.88 | 20.5 | 321 | 2 |

preferentially oriented. The identity and geometry of the important ions in the substrate were not always definitely established and a choice had to be made in some cases. The ion was chosen whose arrangement on the surface best fitted the observed aluminum orientation. For example, the oxygen ions were chosen, instead of the silicon ions, in mica. The calculated binding energy for both is listed in Table 3 for comparison. The atomic polarizabilities were taken from Van Vleck[13] if possible, or calculated,

$$\alpha = \frac{e^2}{4\pi^2 m\omega^2} \qquad [11]$$

where $\omega$ is the characteristic frequency of the atom and the other symbols have the customary significance. The polarizability and characteristic energies for the ions of the alkali halides were taken from Mayer's[14] analytical treatment of the lattice energy characteristics of alkali halides. The validity of the physical constants in this case warranted more extended consideration. A potential energy surface for the system (100) aluminum-sodium chloride was constructed after Orr.[15] It is schematically represented in Fig 15. The potential hole in the center represents a position of the aluminum in which the potential energy is 7 kc per m lower than a position over the cation. The position over the anion corresponds to the highest potential energy on the surface. For this system it is evident that the central site is relatively large but is deeper by 7 kc per m than the next most favorable site and corresponds to a binding energy of approximately 18 kc per m. It is noteworthy that the atoms of the (100) aluminum plane could be laid over the grid formed by the potential energy holes with negligible distortion. The calculations are summarized in Table 3, in which the atom positions, the ionic polarizabilities, the characteristic energies, the dispersion constants and the calculated substrate binding energies are tabulated for thirteen substrate-metal pairs in columns 1 to 7.

Considering the approximations involved in the theory and the uncertainties in the assumed values of $J$ and $r$

*Table 4 . . . Disproportionate Variation of Intensity of Diffracted X ray Radiation with Depth of Penetration*

| (1) | (2) | (3) |
|---|---|---|
| $t$ (Å) | Pct $\frac{t}{t_d}$ | Pct $\frac{I_t}{I_d}$ |
| $5 \times 10^2$ | 1 | 9 |
| $5 \times 10^3$ | 6 | 24 |
| $5 \times 10^4$ | 25 | 53 |
| $1 \times 10^5$ | 50 | 76 |
| $5 \times 10^5$ | 100 | 100 |

one cannot expect, in general, more than an agreement in the order of magnitude between calculated and experimental values. The calculated values ($E_c$) in column 9, Table 2, should be evaluated on that basis. It is considered fortuitous that the calculated values other than for the alkali halides agree as well as they do with the experimental values (column 8). It is significant, however, that the highest values correspond to the substrates upon which the best oriented aluminum films were formed and that the trend definitely agrees with that characteristic of the percent orientation for all eleven substrates and with the indirectly determined substrate binding energies.

It is evident that the periodicity of the potential energy surface of the substrate-atom pair is a very important factor in defining the arrangement of the metal atoms.

## Conclusion

The structure of thin aluminum films condensed in vacuum on clean ionic substrates is strongly influenced by the nature, geometry and temperature of the ions in the base. The degree of orientation of the film with respect to the base can be semiquantitatively correlated with a binding energy characteristic of the substrate. The values of the substrate binding energy are of the same order of magnitude as Van der Waals binding between a single atom and an infinite ionic surface. The characteristics of the film structures show this method to be effective for the preparation of oxide-free oriented aluminum surfaces for studying surface reactions.


## Acknowledgments

The writer is indebted to many of the research faculty for opportunities to discuss the subject and particularly to Professors Charles Barrett, Clarence Zener and Cyril Smith of the Institute for the Study of Metals and to Professor Joseph Mayer of the Institute for Nuclear Studies. In addition, all the structure determinations were made in Professor Barrett's X ray Diffraction Laboratory with the assistance of Messrs. Donald Clifton and James Hess, whose cooperation is gratefully acknowledged.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# P-type and N-type Silicon and the Formation of the Photovoltaic Barrier in Silicon Ingots

J. H. SCAFF,* Member, H. C. THEUERER* and E. E. SCHUMACHER,* Member AIME

The microwave region of the radio spectrum was effectively utilized in radar designs during the recent war and it has become of increasing interest in the field of communications. Work in this field has led to an important use for silicon—that of the point contact rectifiers†[1] in the frequency converter of microwave (radar or radio) receivers—and has stimulated considerable interest in the electrical properties and preparation of silicon and its alloys.

Silicon is an electronic semiconductor. Its conductivity at room temperature results principally from the presence of certain impurities. While for metals an increase in impurity content increases the resistivity, for semiconductors such as silicon the opposite occurs and, in general, the addition of impurities lowers the resistivity. Silicon materials may be classified into one of two groups depending upon the manner in which the impurities contribute to electrical properties. These have been termed for convenience p-type or n-type. P-type silicon develops a very large positive thermal emf against metals, has a Hall coefficient of positive sign and a low resistance direction in point contact rectification with the silicon positive with respect to the point. N-type silicon, on the other hand, develops a negative thermal emf against metals, has a Hall coefficient of negative sign and a low resistance direction in rectification with the silicon negative with respect to the point. Impurities which produce n-type silicon are called donors inasmuch as these elements contribute to electrical conductivity by donating electrons to an unfilled energy band in the silicon. On the other hand, elements which produce p-type silicon are known as acceptors as these impurities contribute to the electrical conductivity by accepting electrons from a filled energy band permitting what is known as conductivity by "holes" in which the sign of the carriers appears to be positive. A general treatment of the mechanism of conduction in semiconductors from the viewpoint of modern band theory has been given recently by Pearson,[2] by Becker, Green and Pearson,[3] and by Torrey and Whitmer.[4]

In this investigation boron and aluminum have been found to be acceptors, and phosphorus, arsenic, and antimony to be donors in silicon. Data on the effect of boron and phosphorus on the electrical properties, when present singly and in combination, have been acquired. These data are discussed in the present paper.

## Raw Materials Used and Methods for Adding Second Constituents

Silicon from two sources was used in this work and these will be referred to as *A* and *B* respectively. Silicon *A* is a material of high purity supplied by the Electro Metallurgical Co. It is prepared by chemical purification of "commercial" silicon obtained from the arc furnace reduction of $SiO_2$. It contains 99.8 pct silicon, minimum, with small amounts of calcium, iron, aluminum, boron, and phosphorus as the principal impurities. This material was extensively employed in these studies as well as in the commercial preparation of rectifier materials. Silicon *B* is a material of high purity from the duPont Co. It is prepared by a pyrolytic reduction of $SiCl_4$ and is free of analytically detectable amounts of boron and phosphorus. Its use permitted study of the effect of boron and phosphorus individually on the properties. This material contains, however, spectroscopic traces of a number of metals, some of which affect electrical and rectification properties.

Typical analyses for the two grades of silicon are given in Table 1.

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TP 2586 E. Discussion of this paper (2 copies) may be sent to *Transactions* AIME before November 15, 1949. Manuscript received January 24, 1949.

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† These are, essentially, the modern version of the "crystal detector" in which rectification is obtained by applying a point contact to the surface of a semiconductor.

[1] References are at the end of the paper.

*Table 1 . . . Analyses of Silicon Used in Point Contact Rectifier Investigations*

| | Silicon *A*† | Silicon *B* |
|---|---|---|
| Si | 99.84 | |
| Ca | 0.003 | 0.005* |
| Na | | 0.005* |
| Cu | | 0.001* |
| Mg | 0.007 | 0.001* |
| Mn | 0.002 | 0.001* |
| Al | 0.020 | Not detected |
| Fe | 0.031 | 0.03* |
| C | 0.019 | |
| O | 0.061 | |
| H | 0.001 | |
| N | 0.008 | |
| P | 0.011 | Not detected |
| B | 0.005 | Not detected |

* These are estimated upper limits as determined by spectrographic methods.
† Analysis furnished through the courtesy of Mr. E. F. Doom, Union Carbide and Carbon Research Laboratories, Inc.

To make controlled additions of boron to the charge it was necessary to employ a low boron content master alloy since the quantity of boron to be added was usually only a few thousandths of one percent. The alloy containing nominally one percent boron was prepared by melting chemically pure boron with silicon *A* using the melting techniques for 320 g silicon

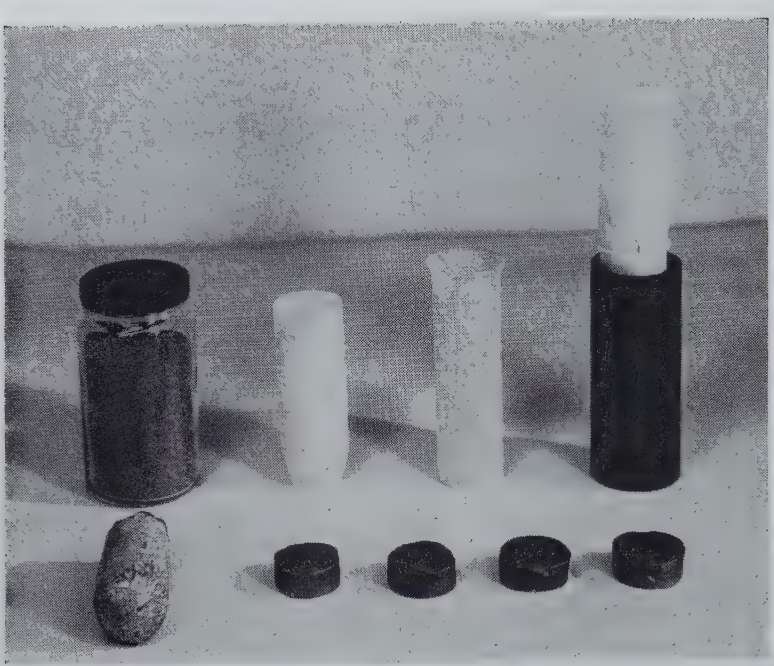


**FIG 1*a*—Silicon ingot preparation.**
Silicon granules and crucible arrangement in background. Ingot and ingot sections in foreground.


**FIG 1*b*—Longitudinal section of 320 gram silicon ingot.**

ingots to be described in the next section. This alloy was crushed in a hardened steel die, ground to a fine powder in an agate mortar, thoroughly mixed and analyzed for boron. Portions of this master alloy were then used in preparing the experimental ingots.

Direct additions of phosphorus were not feasible because of its low melting point and volatility. Instead use was made of the reaction:

$$2Ca_3(PO_4)_2 + 5\ Si = 6\ CaO + 4P + 5\ SiO_2$$

When this method was used, spectrochemical analysis revealed that no calcium was retained by the silicon. Apparently also, calcium oxide formed by the reaction does not affect the properties, for the direct addition of calcium oxide to silicon ingots caused no changes in either rectifying characteristics or resistivity.

Additions of aluminum, arsenic and antimony for the qualitative tests described were made by adding these elements directly to the furnace charge.

## PREPARATION OF SILICON INGOTS

The ingots of silicon were prepared in silica crucibles in an atmosphere of helium in a high frequency induction furnace. Since silicon cannot be heated by direct induction, a graphite heater which fitted around the melting crucible was used. Most of the early work was done with 45 g ingots. In preparing the ingot the charge was fused and then slowly cooled by reducing the power applied to the induction coil. Freezing occurred largely from the top surface downward and to a lesser extent inward from the sides and upward from the bottom. During freezing, normal impurity segregation occurred. That is, the silicon at the top of the ingot was highest and that at the core of the melt was lowest in purity.

It was difficult to produce crack-free ingots by this method because of the expansion of silicon during solidification. If a mass of silicon is allowed to freeze in the normal manner, in the final stages of freezing a liquid core will be surrounded by a solid shell which may be easily ruptured by the expansion of the freezing liquid. By changes in solidification technique, however, means were found for preparing 320 g ingots free of cracks throughout the major part of the ingot. Such ingots were prepared in cylindrical silica crucibles of 1¾ in. diam and 5 in. tall. Melting was accomplished in the same manner as for the smaller charges, using graphite heaters, but freezing was controlled by gradually removing the furnace tube from the induction coil while power was still applied to the coil. Thus the top of the melt froze first, and solidification progressed slowly downward, the total time for solidification being about 20 min. This not only avoided cracking but gave precise control over impurity distribution in the ingot. Due to segregation of impurities, the silicon at the top of the ingot had the highest purity, while the last material to freeze, at the bottom portion of the ingot, had the lowest purity. Fig 1*a* shows the crucible assembly, a typical 320 g silicon ingot and several sections cut from an ingot. The macrostructure of the ingot is shown in the longitudinal section, Fig 1*b*.

## ELECTRICAL CHARACTERISTICS AND STRUCTURAL FEATURES OF THE EARLY SILICON INGOTS

The early ingots (45 g) prepared from selected lots of silicon *A* were found to consist of zones of p-type and n-type separated by a photovoltaic barrier.[5] The p-type zone was located in the region of the ingot which solidified first while the n-type zone was located in the region of the ingot which solidified last. The macrostructure of the ingots is illustrated in the diagram, Fig 2. Relatively large columnar crystals extend downward from the top surface of the ingot to a depth of about one-half inch. Columnar grains are also found extending inward from the sides and upward from the bottom for about one-eighth inch. Beyond the columnar grains irregular grains are found with a network of a second phase in the grain

boundaries. The central portion of the ingot is porous presumably as a result of gas evolution in the last stages of solidification. The outer part of the columnar zone is p-type, the inner part n-type. The central portion of the ingot, containing the irregular grains is also n-type. The boundary between the p- and n-zones is approximately 1 mm in width and extends across the columnar grains, following in general the contour of the ingot surface. Since solidification occurred not only from the top surface downward but also to some extent inward from the bottom and sides of the crucible, the boundary is elliptical in cross-section and encloses the n-zone. It is evident that the boundary follows the contour of the freezing surface as it advanced during solidification. In the 320 g ingots similar effects are observed. However, in this case the solidification of the melt is substantially unidirectional, progressing from the top surface downward. The boundary then extends across the ingot and the portion of the ingot above it is p-type and below it is n-type.

If ingots are rapidly cooled by shutting off the power in the induction coil when the charge has melted, the resulting macrostructure is quite different. The crystallites are no longer columnar but are quite irregular in shape. In each grain an island of p-type is found within a matrix of n-type. The p- and n-zones are again separated by a barrier layer, but the photovoltages developed are lower than those for the barriers of the slowly cooled ingots. The structures of both the rapidly and slowly cooled ingots may be resolved microscopically and are discussed in a companion paper.[6]

Photovoltaic cells may be prepared from the slowly cooled ingots by cutting samples so that one part is p-type, the other n-type separated by the barrier. Such cells are sensitive both to visual and infra-red radiation. They are quite stable and have shown no change in characteristics over a period of several years. Moreover, the effect persists even after annealing at 1000°C for a number of hours.

Associated with the internal photovoltaic boundary are two related effects of interest. Specimens containing these boundaries show both a rectification effect and a pronounced thermoelectric effect. The rectification effect is similar to that obtained in copper oxide or selenium cells. In specimens containing these internal boundaries rectification

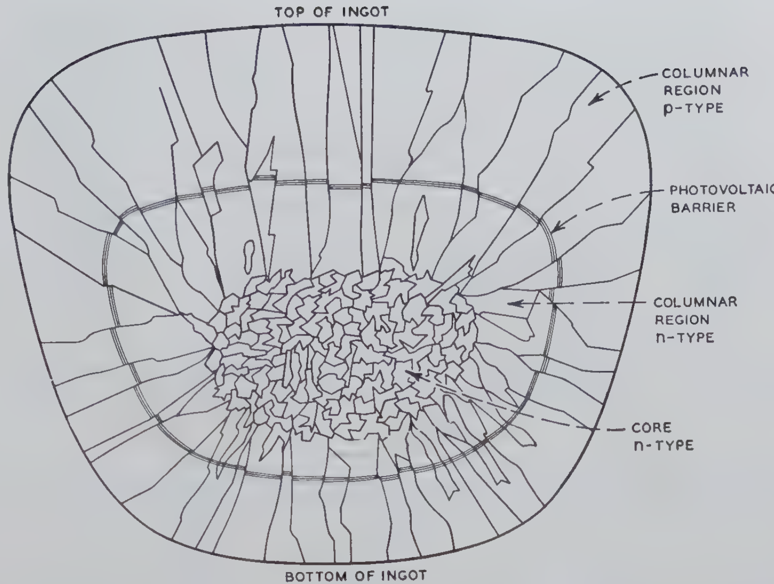



**FIG 2—Schematic representation of 45 gram silicon ingot showing barrier.**

ratios above 500 at 1 volt have been obtained. Similar rectification and photovoltaic effects in germanium have been reported by Benzer.[7]

Measurement of the resistivity of the silicon at different positions in the ingots containing p-n boundaries revealed an interesting relationship. Since increasing the concentration of impurities in semiconductors decreases the resistivity and since chemical analysis had shown the segregation of impurities in the ingots to be normal it was expected that the resistivity would decrease steadily from a high value for the material which solidified first to a lower value for the material which solidified last. Instead it was observed that in the p-region the resistivity was least for the first frozen material and that it increased with depth to a high value at the barrier. In the n-region the resistivity was highest near the barrier and then decreased with distance from the barrier reaching its lowest value in the region of the ingot which solidified last. The variation in resistivity in the p- and n-zones of a 320 g ingot is shown in Curve 1, Fig 3, which will be discussed at a later point in the paper.

Several other significant facts were observed in the early studies. For a given lot of silicon *A* the location of the barrier and the relative amounts of p- and n-silicon were precisely reproduced from ingot to ingot but differences were obtained between lots. The mean resistivity in the p-silicon was also related to the location of the barrier and in general it decreased as the amount of p-silicon in the ingot increased. This clearly indicated the important role of impurities in determining properties and led to a detailed study of the electrical properties of silicon containing different alloying constituents in trace amounts.

## EFFECT OF BORON ON THE RESISTIVITY AND RECTIFICATION CHARACTERISTICS OF SILICON

To obtain quantitative data on the effect of boron on resistivity and the rectification properties ingots were made with boron additions ranging from 0 to 0.01 pct. These ingots were prepared using 320 g charges of silicon *A* mixed with appropriate quantities of the silicon-boron master alloy. The resistivity measurements were made on rectangular specimens, approximately $1 \times \frac{1}{8} \times \frac{1}{8}$ in. in size. These were cut from the ingots so that the long axis was parallel to the top surface of the ingot. Current leads were affixed to the ends of the specimen by electroplating with nickel and soldering. The potential drop across probes on the surface of the specimen was then determined for small known currents by a potentiometric method. From these data, the dimensions of the sample and the distance between probes, the resistivity may be calculated. The sign of rectification, that is, whether the silicon was p- or n-type, was determined by applying a point contact to the surface of the specimen and observing the polarity for the easy direction of current flow.

The resistivities of the central sections of the specimens were determined for a number of vertical positions in

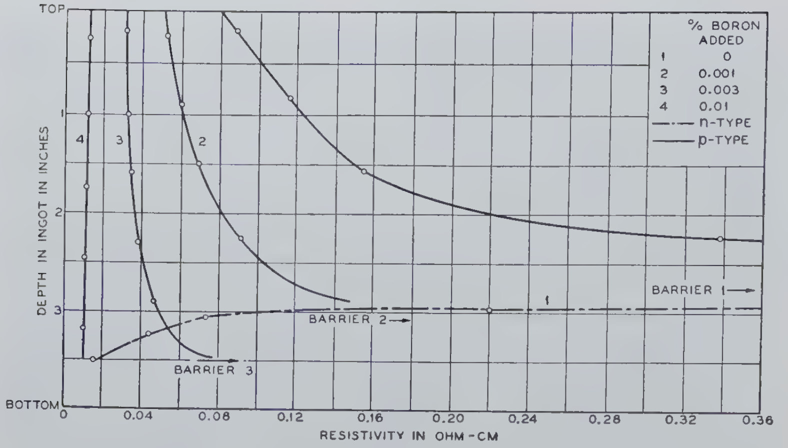



FIG 3—Effect of boron additions on the electrical properties of silicon *A*.

each ingot. Resistivity measurements in the n-region were possible, however, only for the initial sample in the series to which no boron was added. In the other ingots the n-region was too restricted in size to permit several points to be obtained.

These data are plotted in Fig 3. It will be seen that within this composition range increasing the concentration of boron in silicon *A* has three significant effects: 1. It increases the amount of p-silicon and lowers the position of the barrier (Curves 1, 2 and 3); if sufficient boron is added only p-type is formed (Curve 4). 2. It lowers the mean resistivity of the silicon. 3. It increases the uniformity of resistivity for a considerable part of the material in the ingot and for the 0.01 pct boron addition substantially no variation is observed throughout the ingot (Curve 4).

In the preparation of silicon point contact rectifiers the uniformity of the finished rectifiers is determined to a considerable extent by the uniformity of resistivity of the silicon used. It was desirable for this reason to attain the uniformity of the 0.01 pct boron composition at higher levels of resistivity also. To determine whether this could be achieved in silicon of higher purity, several ingots were prepared from silicon *B*. After fusion without alloying additions this material is p-type and its specific resistance is of the order of one ohm-cm. Addition of 0.001 pct boron, however, markedly lowers its resistivity as shown in Curve 1, Fig 4. The resistivities for this alloy ranged from 0.07 ohm-cm at the top of the ingot to about 0.03 ohm-cm at the bottom. Thus no improvement in uniformity of resistivity was obtained by the use of silicon of extreme purity as the base material. It will be noted, however, that the resistivity *decreased* with depth in the ingot. Hence, in silicon containing only boron as the principal alloying constituent the variation of resistivity in the ingot is in the manner to be expected from a normal segregation. This is in contrast to the increase in resistivity with depth observed in ingots of silicon *A* containing comparable amounts of boron.

## EFFECT OF BORON AND PHOSPHORUS ON THE PROPERTIES OF ULTRA-HIGH PURITY SILICON

To explain the anomalous resistivity gradient observed in ingots of silicon *A* the presence of a second active impurity which also affected conductivity was assumed. Further investigations revealed that traces of phosphorus were responsible for the anomalous resistivity variations and the formation of n-silicon and the photovoltaic boundary in the ingots of this material.

To study the effects in silicon of phosphorus and boron in combination, a number of alloys were prepared from silicon *B*. Specimens were cut from these ingots through the central vertical axis and the resistivity and direction of rectification then determined at ⅛ in. intervals. The data for typical alloys are given in Table 2 and Fig 5.

### Table 2 . . . Resistivity of Silicon-boron and Silicon-Phosphorus Alloys

| Composition | | Resistivity at Room Temperature of Samples from Different Locations in the Ingot | | |
|---|---|---|---|---|
| | Pct | Top ohm-cm | Middle ohm-cm | Bottom ohm-cm |
| Silicon B | +0.001 B | 0.067 | 0.050 | 0.040 |
| Silicon B | +0.01 B | 0.015 | 0.011 | 0.006 |
| Silicon B | +0.0029 P* | 0.041 | 0.034 | 0.017 |
| Silicon B | +0.0058 P* | 0.031 | 0.023 | 0.008 |

* Added as $Ca_3(PO_4)_2$.

These data show that:

1. The addition of boron to pure silicon produces p-silicon while the addition of phosphorus produces n-silicon. The resistivity of such alloys decreases with increasing concentration of the added element (Table 2 and Curves 1 and 2).

2. If ingots of silicon containing either boron or phosphorus are prepared by freezing from the top surface downward, normal segregation occurs and as a result the resistivity decreases with depth in the ingot. The rate of segregation of phosphorus is somewhat greater than that of boron as shown by a more steeply sloping resistivity curve (Curves 1 and 2).

3. If in silicon containing both boron

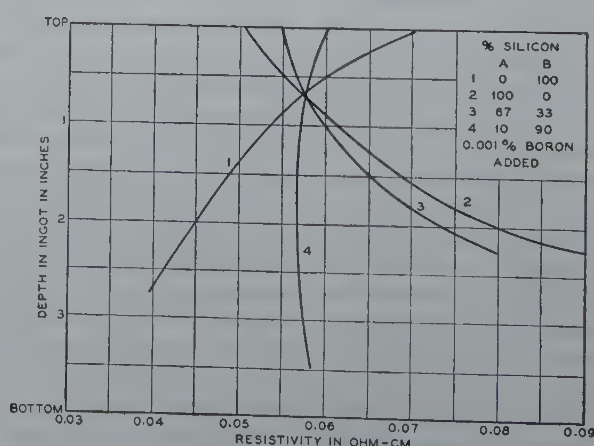



FIG 4—Resistivities of various alloys of silicons *A* and *B*.

and phosphorus, the boron exceeds the phosphorus by a small molar amount, of the order of 0.0002 pct, and the ingot is prepared by solidifying slowly from the top downward, then zones of p- and n-silicon will be formed, separated by the photovoltaic boundary (Curve 3). It is therefore possible to reproduce completely the resistivity, rectification and other properties observed for silicon *A* by adding the correct relative amounts of boron and phosphorus to silicon *B*. Since boron and phosphorus are both present in silicon *A* it is a reasonable conclusion therefore that they are the principal impurities responsible for the electrical effects observed in this material.

The mechanism of formation of the p- and n-zones and the barrier may now be interpreted in terms of an electrical interaction or compensating effect of equivalent amounts of donor and acceptor impurities. Referring to Fig 6, Curves 1 and 2 are hypothetical segregation curves for boron and phosphorus with phosphorus segregating more rapidly than the boron. At a depth of 3 in. in the ingot the curves cross and at this point the molar concentrations of boron and phosphorus are equal. Since it is believed that these impurities neutralize one another electrically, no residual impurities are available at this point to contribute to the conductivity of the silicon.* As a result high resistivity and poor point contact rectification are to be expected. This is actually the case in the region of the barrier. Above this region boron is in excess by an amount which is indicated by the difference between the two segregation curves at each location in the ingot. This amount is given by Curve 3, Fig 6 which shows that the free (excess) boron decreases with depth in the ingot from a value of 0.001 pct at the top to 0 pct at the barrier. Since boron is in excess the silicon is p-type, and since the concentration of free boron diminishes with depth, the resistivity increases correspondingly. Below the barrier phosphorus is in excess of boron by an amount equal to the difference between their concentrations at each location. The concentration of free phosphorus below the barrier, given by Curve 4, Fig 6, increases from 0 at the barrier to 0.0015 pct at the bottom of the ingot. Since phosphorus is in excess in this region the silicon is n-type and its resistivity decreases with depth in the ingot.

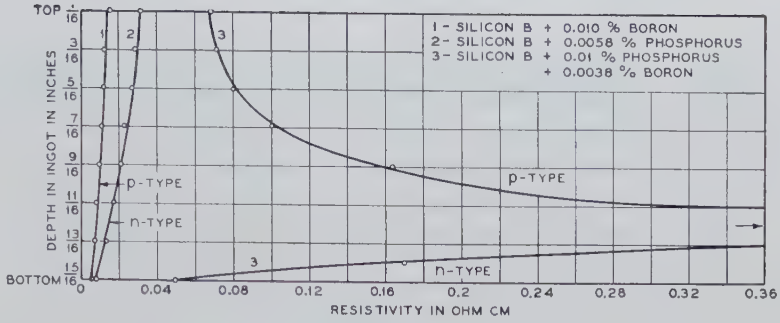
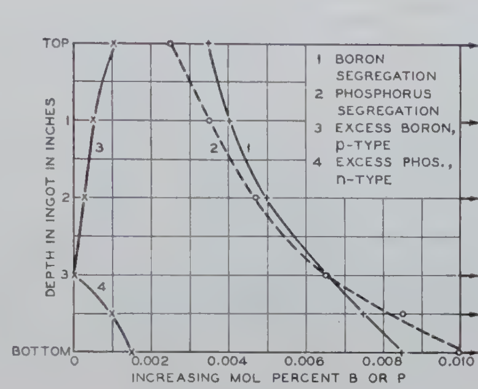



FIG 5—Effect of boron and phosphorus on the electrical properties of silicon *B*.




| B | P | EXCESS B | EXCESS P |
|---|---|---|---|
| 0.0035 | 0.0025 | 0.001 | |
| 0.004 | 0.0035 | 0.0005 | |
| 0.005 | 0.0047 | 0.0003 | |
| 0.0065 | 0.0065 | 0 | 0 |
| 0.0075 | 0.0085 | | 0.001 |
| 0.0085 | 0.010 | | 0.0015 |

FIG 6—Mechanism of formation of barrier in silicon ingots.

If silicon having the characteristics of Fig 6 were remelted and 0.001 pct more boron were added, the boron segregation Curve No. 1, would shift to the right and would intersect the phosphorus curve at a lower point. Thus, the photovoltaic barrier would appear at a lower point, the amount of p-silicon would be increased, and, since the excess of boron at the top of the ingot would also increase, the mean resistivity of the p-silicon would be lower. If instead, the boron concentration were held constant and the concentration of phosphorus reduced, Curve 2 would shift to the left, and again, the barrier would have occurred lower in the melt, the free boron concentration above the barrier would have increased and the mean resistivity would have been lowered.

It may be seen, therefore, that the electrical characteristics of the silicon ingots may be explained in terms of the differential segregation of boron and phosphorus. The hypothesis has not been checked by direct analysis, however, because of difficulties in determining accurately the small concentrations of boron, and phosphorus at the different locations in the ingot. It is believed, however, that the hypothetical values given in Fig 6 are correct as to order of magnitude.

While these studies have been concerned principally with boron and phosphorus in silicon it has also been shown that aluminum additions produce p-type silicon, while arsenic and antimony produce n-type silicon. Moreover, photovoltaic barriers have been produced by the addition of arsenic to silicon *B*. It seems to be generally true therefore that the addition to silicon of elements of group 3, with 3 valence electrons produces p-silicon while elements of group 5, with 5 valence electrons, produces n-silicon.

## DEPENDENCE OF UNIFORMITY OF RESISTIVITY ON THE BORON PHOSPHORUS RATIO

It has been shown that in silicon ingots containing only one principal impurity, the resistivity varies with location in the ingot. On the other hand, if 0.01 pct boron is added to silicon *A* practically no variation in resistivity is observed throughout the ingot. This suggested that uniformity of resistivity throughout the ingot might be related to the relative

* Similar phenomena have been reported in lead sulphide photoconductive cells by Starkiewicz, Sosnowski, and Simpson[8] and by Sosnowski, Soole, and Starkiewicz.[9]

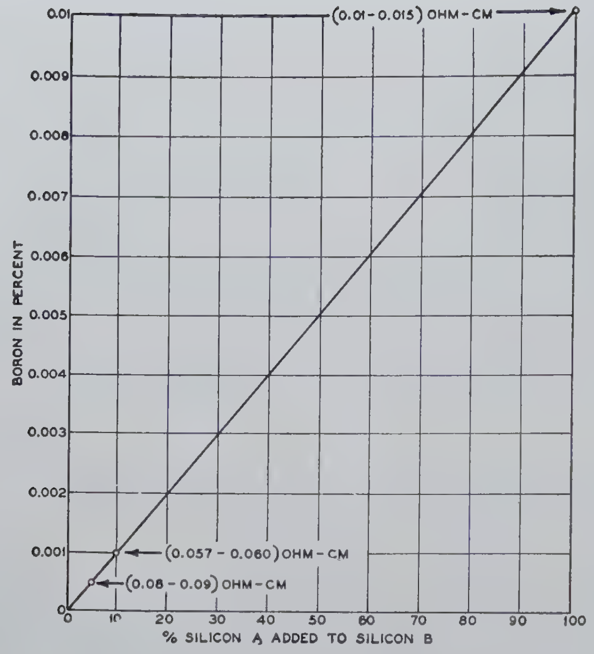



**FIG 7—Boron additions to various mixtures of silicon *A* and *B* to obtain uniform resistivity in silicon ingots.**

The values in parenthesis are the resistivity ranges observed for each composition.

amounts of boron and phosphorus in the charge and that under the correct conditions the uniformity of the 0.01 boron composition might also be attained in materials of high resistivity. To check this experimentally several melts were prepared using as raw materials different proportions of the silicons *A* and *B*, adding 0.001 pct boron to each charge. Since the *A* silicon contained both boron and phosphorus while the *B* silicon is free of analytically detectable quantities of these elements this series provided samples with a range of boron and phosphorus concentrations in which the relative proportions were systematically varied in the direction of increasing the boron to phosphorus ratio.

Resistivity as a function of location in the ingot for this series is plotted in Fig 4. As the concentration of phosphorus is decreased by increasing the proportion of silicon *B* in the charge, the variation in resistivity with depth decreases. The least variation is obtained with the 90-10 composition.

Thus, uniform ingots of silicon of desired resistivity may be prepared by making the proper boron additions and maintaining a critical boron to phosphorus ratio. This ratio is about 5 boron atoms for each phosphorus atom. Fig 7 shows the amounts of boron which must be added to various mixtures of silicons *A* and *B* to maintain the required 5 to 1 ratio and gives the resistivity range obtained in each ingot. It will be seen that sensibly uniform ingots with any resistivity desired in the range from 0.01 to 0.1 ohm-cm may be obtained in this way. These proportions would vary slightly if the composition of silicon *A* changed significantly from lot to lot.

## Summary

Boron and aluminum are acceptors in silicon, and phosphorus, antimony, and arsenic are donors forming respectively p-type or n-type silicon. The presence of boron or phosphorus alone markedly reduces the specific resistance of silicon. If ingots of silicon containing small amounts of either boron or phosphorus are solidified from the top downward, normal segregation occurs and the resistivity decreases with depth in the ingot. If boron and phosphorus are present together in certain amounts, ingots may be prepared in which the top section is p-type and the bottom is n-type silicon, in which a barrier region with interesting rectification and photovoltaic properties separates the p-type and n-type regions. In the p-zone the resistivity increases rapidly as the barrier is approached, reaches a maximum at the barrier and then decreases in the n-zone. The formation of the barrier and the variation of resistivity with depth in the ingot are interpreted as being due to interaction between donors and acceptors, in this case boron and phosphorus, in which one mol of boron compensates one mol of phosphorus. Boron and phosphorus segregate at different rates under the solidification conditions used so that in the region of the ingot which solidifies first boron is in molar excess and the silicon is p-type. In the region which solidifies last phosphorus is in molar excess and the silicon is n-type. At the location in the ingot where the molar concentrations of boron and phosphorus are equivalent, the barrier is found.

Addition of phosphorus to boron silicon compositions improves the uniformity of the resistivity in the ingot. In spite of the extreme sensitivity of the resistivity to impurities means were found to obtain sensibly uniform resistivities by maintaining the correct boron to phosphorus ratio.

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# Microstructures of Silicon Ingots

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## Introduction

The effects of impurities on the electrical properties of silicon are discussed in a companion paper by Messrs. Scaff, Theuerer, and Schumacher.[1] It was shown that an ingot of silicon which contained boron and phosphorus in certain concentrations consisted partly of p-silicon and partly of n-silicon[2] and that the common boundary between these regions was the source of a photovoltage. These features were ascribed to the segregation of boron and phosphorus during solidification of the ingot. Because of different rates of segregation the first portion of the ingot to freeze contained a molar excess of boron over phosphorus and hence was p-silicon. The last-solidified region contained a molar excess of phosphorus and was n-silicon.

This paper is concerned with the microscopic examination of such ingots. The microstructures are rather unusual in certain respects and their study has helped to show how the segregation of minor elements modifies the electrical properties of silicon. The microstructures of ingots prepared from two lots of silicon, designated 1 and 2, will be described. These lots were obtained from the Electro Metallurgical Co. Both contain 99.8+ pct silicon, but they differ in impurity analysis. For each lot will be shown the microstructure of a slowly cooled ingot, for which the time of solidification is 6 min., and that of a rapidly cooled ingot, for which the time of solidification is 2 min. The ingots were prepared from 45 g charges of silicon.

When an alloy freezes a cored structure is generally produced because of insufficient diffusion to remove concentration differences established during freezing. As a result of coring the first portion of a crystal to freeze is usually poorer in solute than equilibrium requires, while the last material to solidify is richer. In a columnar grain, growth is principally unidirectional and coring can produce a concentration gradient along the entire grain. By carrying the picture of the coring process from a single grain to an entire ingot in which columnar grains are aligned more or less radially, one can easily see that a composition gradient could be established between the outside and center of the ingot. This, to a considerable extent, occurs during the solidification of a slowly cooled ingot of silicon.

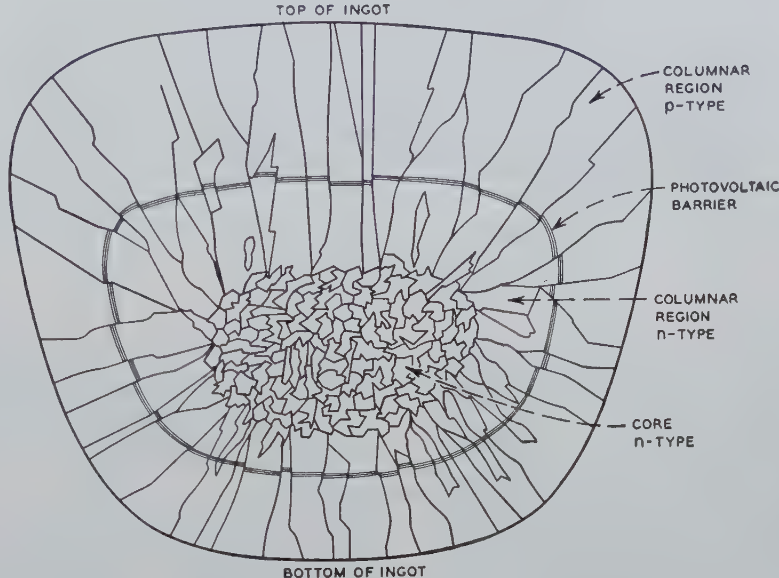


**FIG 1—Sketch showing features of slowly-cooled ingot of silicon.**
Vertical section through center of ingot.

## Slowly Cooled Ingot

In slowly cooled ingots of both lots of silicon, columnar grains which are approximately radial in direction and longest at the top of the ingot enclose a region in which the shapes and alignment of the grains are considerably less regular. The central region is last to solidify and contains cavities and inclusions. The sketch of Fig 1 illustrates some of these features, as well as others which will be described below.

If a polished section of an ingot is etched in a mixture of 2 parts of 20 pct HF and 98 parts of $HNO_3$ the p-n barrier becomes visible. The overall shape of the barrier in a slowly-cooled ingot is roughly oval, as may be seen in Fig 1. The proportion of n-silicon, that is, the region enclosed by the barrier, is considerably greater in ingots of lot 1 than in those of lot 2.

A sample about ½ × ⅛ × ⅛ in. was cut from a slowly cooled ingot of lot 1 with its long direction extending from the top of the ingot to the porous region. Thus its upper half was p-silicon, its lower half n-silicon. A longitudinal face was polished and etched in the acid mixture. The areas of interest are identified in Fig 2. A band of parallel markings extends across the sample in the columnar region. These striae are roughly parallel to the upper surface of the ingot and cross grain boundaries with only slight deviations. They are quite distinct in the n-silicon,

Cleveland Meeting, October 1949.
TP 2587 E. Discussion of this paper (2 copies) may be sent to *Transactions* AIME before November 15, 1949. Manuscript received Jan. 24, 1949.

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[1] J. H. Scaff, H. C. Theuerer, E. E. Schumacher: "P-type and N-type Silicon and Formation of the Photovoltaic Barrier in Silicon Ingots." *Metals Transactions*, this volume, p. 383.

[2] The reader is referred to Ref. 1 for definitions of p- and n-type semiconductors and of donor and acceptor impurities.


**FIG 2—Longitudinal section of slowly-cooled ingot of lot 1. Etched in acid mixture. × 14.**
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aries. The striae in the columnar region are believed to be the result of minor undulations in the composition gradient which are caused by disturbances in the liquid adjacent to the advancing solid. They record the positions of the liquid-solid interface throughout the solidification of the columnar region. Since an overall concentration gradient of impurities is established during the freezing of the columnar grains the striae may also be regarded as contours of constant composition.

An explanation of the alternating strips of p-silicon and n-silicon at the boundary is given by the hypothetical curve of Fig 4, which shows the concentrations of *excess* boron or phosphorus as a function of distance from the top of the ingot for a single columnar grain. The reversals represent the local variations in composition which are associated with the striae, while the major trend of the curve depicts the general effect of coring on the *difference* between the concentrations of phosphorus and boron. Since silicon changes from p-type to n-type at zero difference, it is possible to have a number of alternate bands of p-silicon and n-silicon in a polished section if the fluctuations are of sufficient amplitude. This situation is shown in Fig 4, where two narrow strips of p-silicon and two of n-silicon appear, and is a characteristic feature of slowly cooled ingots, as may be seen from Fig 5 and from Fig 2 and 3. The dark edges between the p- and n-areas in Fig 5 do not necessarily indicate the presence of a substance at the boundary but are an

especially near the p-type area. Striae are present in the p-silicon but are not visible in Fig 2.

Photovoltaic activity is confined to points on the sample which are common to both p- and n-silicon. It was possible to determine the locations of such points very accurately by connecting a suitable recording instrument to the ends of the sample and then exploring the specimen surface at high magnification, using the illuminating beam of the microscope as a source of light.

A portion of the p-n region of Fig 2 is shown at higher magnification in Fig 3.

Examination of Fig 2, 3 and 5 will show that although a few n-striae are completely isolated, most of the n- and p-striae are connected to the main bodies of n- and p-silicon respectively. The striae may be said to be interlocking rather than alternating. Hence the boundary which is common to the main bodies of n- and p-silicon is quite long. A result of this feature is an enhancement of the photo-current obtained on illumination.

The difference in the behavior of the two etchants which have been used in this study is interesting. A warm, aqueous, 5 pct solution of sodium hydroxide forms etch-pits whose shapes depend on crystal orientation. At moderate and low magnifications this effect is seen as a uniform darkening of entire grains which varies in degree in individual grains. Hence this reagent is helpful in showing grain size and shape. It is entirely insensitive, however, to the presence of the p-n boundary or the effect which produces the striae.

On the other hand the mixed acid etchant reveals the striae and the p-n boundary. It produces an overall brightening and delineates the grain boundaries.

The following explanation is advanced for the microstructures of a slowly cooled ingot:

When freezing begins columnar grains form at the outside of the melt and grow inward, those originating at the upper surface growing most rapidly. At any time during solidification the shape of the liquid-solid interface roughly parallels the outer surface of the ingot. This advancing front is more or less unbroken except for small differences in growth of individual grains and irregularities at the grain bound-

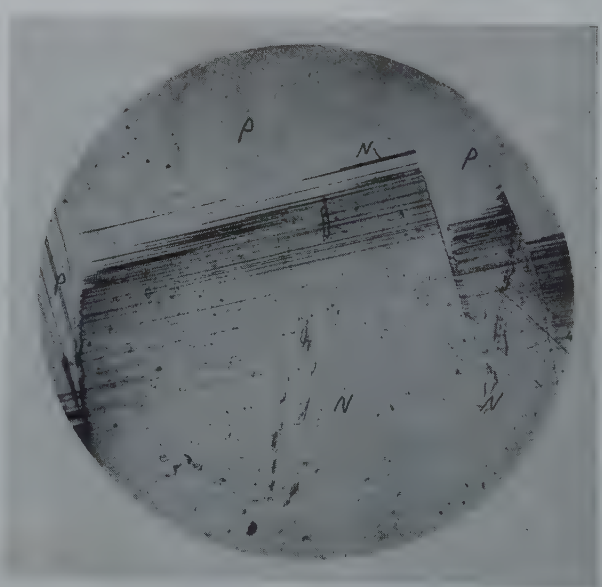


**FIG 3—Area from Fig 2. × 50.**
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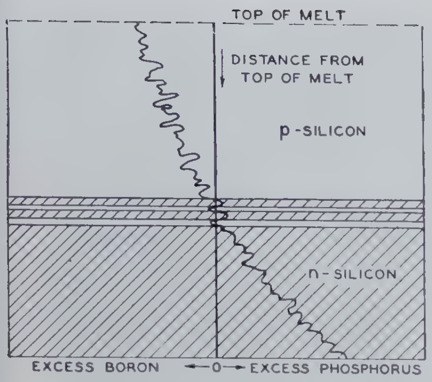


**FIG 4—Relation between excess impurity concentration and distance from top of ingot.**

etching effect. The p-silicon is attacked more rapidly by the acid etchant, leaving raised peninsulae of n-silicon whose sides are oblique, and hence are dark in vertical illumination.

## Rapidly Cooled Ingot

If the molten silicon is cooled rapidly, nucleation occurs throughout the melt rather than only at the surface and instead of columnar crystals an equiaxed grain structure results. Such an ingot differs from a slowly cooled ingot electrically and microstructurally. During solidification coring produces at the center of each grain a region which is poor in impurities and which is surrounded by layers of increasingly higher concentration. In contrast, the region weak in impurities in a slowly cooled ingot is at the outside of the ingot and is continuous. In a rapidly cooled ingot inclusions are found in the last-solidified parts of each grain and are distributed throughout the ingot instead of being concentrated in the center, as in a slowly cooled ingot. In short, in a slowly cooled ingot segregation may be regarded as a feature of the ingot as a whole, while in a rapidly cooled ingot it is in general localized to individual grains.

If the relative concentrations of boron and phosphorus vary in a single grain as they do in a slowly cooled ingot, one would expect to find a p-n boundary having the shape of a closed figure in that grain. Examination of rapidly cooled ingots has shown this to be so. The microstructures may be described as islands of p-silicon in a background of n-silicon. Measurements of the direction of point contact rectification, made by using a sharply pointed probe to touch individual grains, showed that invariably the islands were p-silicon while the surrounding areas were n-type.

Fig 6 shows an area in a rapidly cooled ingot of lot 1 in which several islands of p-silicon are visible. These islands were concentrated at the top of the ingot where, despite the noncolumnar grain growth, freezing did take place first. The remainder of the ingot was entirely n-type. Thus, in addition to local coring in each grain, some segregation had occurred in the ingot as a whole.

An area from a rapidly cooled ingot of lot 2 is shown in Fig 7 and 8. Here the p-n boundaries are near the grain boundaries. The major part of each grain is p-silicon surrounded by a thin strip of n-silicon. Again some segregation occurred over the ingot as a whole, as some grains at the top of the ingot contained only p-silicon and the grains containing the greatest proportion of n-silicon were at the center of the ingot.

It was stated in the discussion of slowly cooled ingots that those of lot 2 contained more p-silicon than those of lot 1. As Fig 6 and 7 show, this relationship is also true for the individual grains in rapidly cooled ingots.

Although the p-n boundaries in the two types of ingot are unlike in many respects, they are basically similar. Their shapes and locations differ because the ingots solidify in dissimilar ways. The appearance of the boundary in a slowly cooled ingot is further modified by the effect responsible for the striae. Apparently this effect is seldom present in rapidly cooled ingots.

The irregular shapes of the p-n boundaries, especially in rapidly cooled ingots, make it unlikely that they are localized to certain crystallographic planes. Their locations and appearance at high magnification distinguish them from grain boundaries. Illustration of these points is offered in Fig 9 and 10.

## Summary

The microstructures of ingots of two lots of silicon have been described, both as prepared by slow cooling and by rapid cooling. The dependence of the distribution of the p- and n-regions on segregation has been indicated. When the ingot freezes slowly the grains are columnar, the regions of p-silicon form

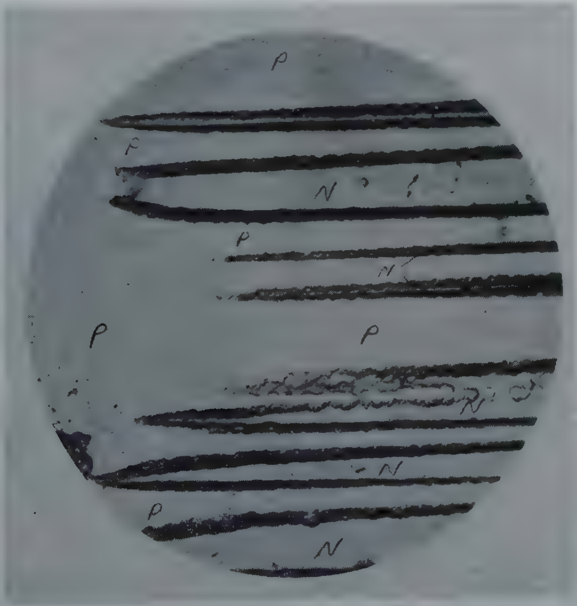


**FIG 5—Interlocking strips of n- and p-silicon in slowly-cooled ingot of lot 1. × 1000.**
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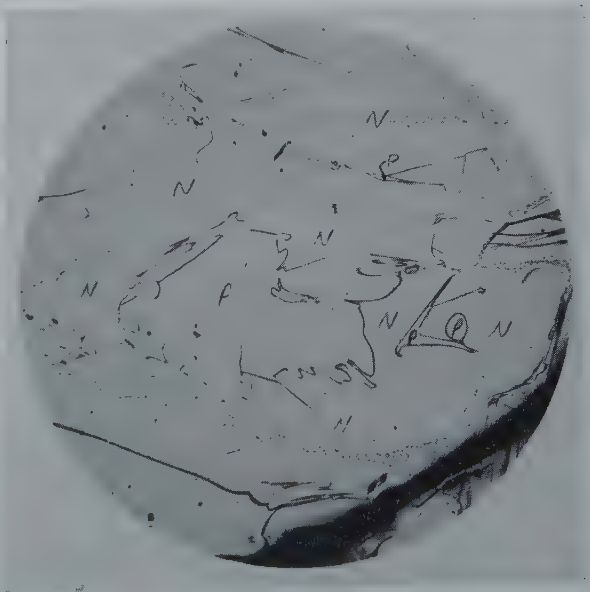


**FIG 6—Rapidly-cooled ingot of lot 1. Etched in acid mixture. × 50.**
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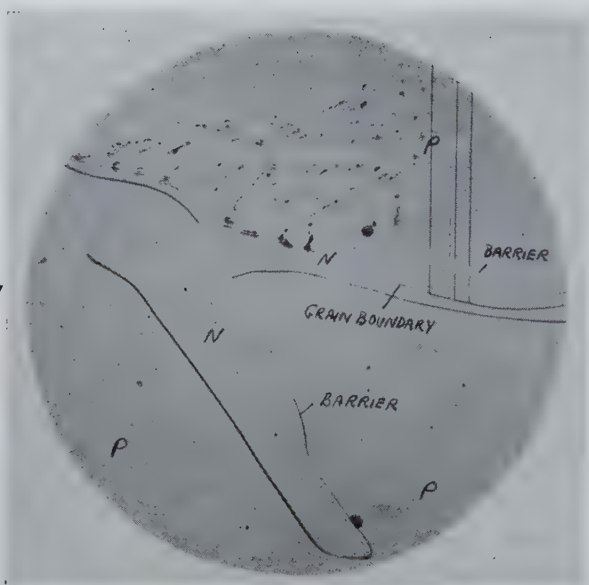


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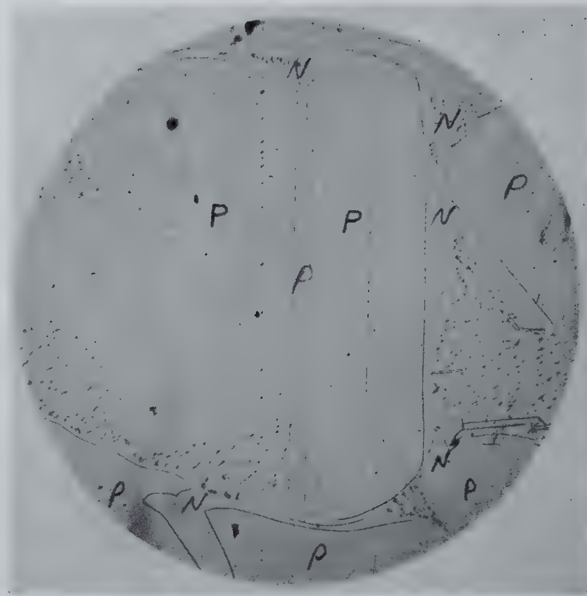


**FIG 7—Rapidly-cooled ingot of lot 2. Etched in acid mixture. × 100.**
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**FIG 8—Area from Fig 7 showing two p-n barriers separated by a grain boundary. Oblique illumination. × 250.**
Reduced approximately one-third in reproduction.

**FIG 9—P-N barrier in rapidly-cooled ingot of lot 1.**
Note irregular shape and variation in thickness. Etched in acid mixture. ×500. Reduced approximately one third in reproduction.

a continuous zone which encompasses the n-silicon, and the p-n boundaries are relatively continuous. When cooling is more rapid, nucleation occurs throughout the melt and grain growth is disorderly, with the result that the p-silicon and the p-n boundary in each grain are separated from the corresponding regions in adjacent grains by layers of n-silicon.

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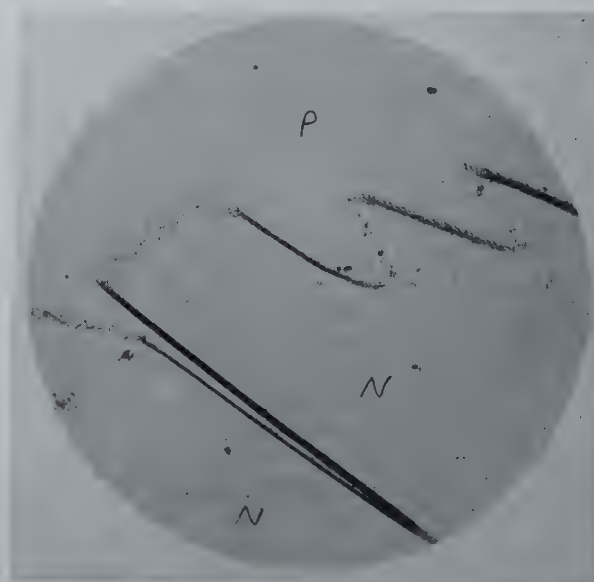


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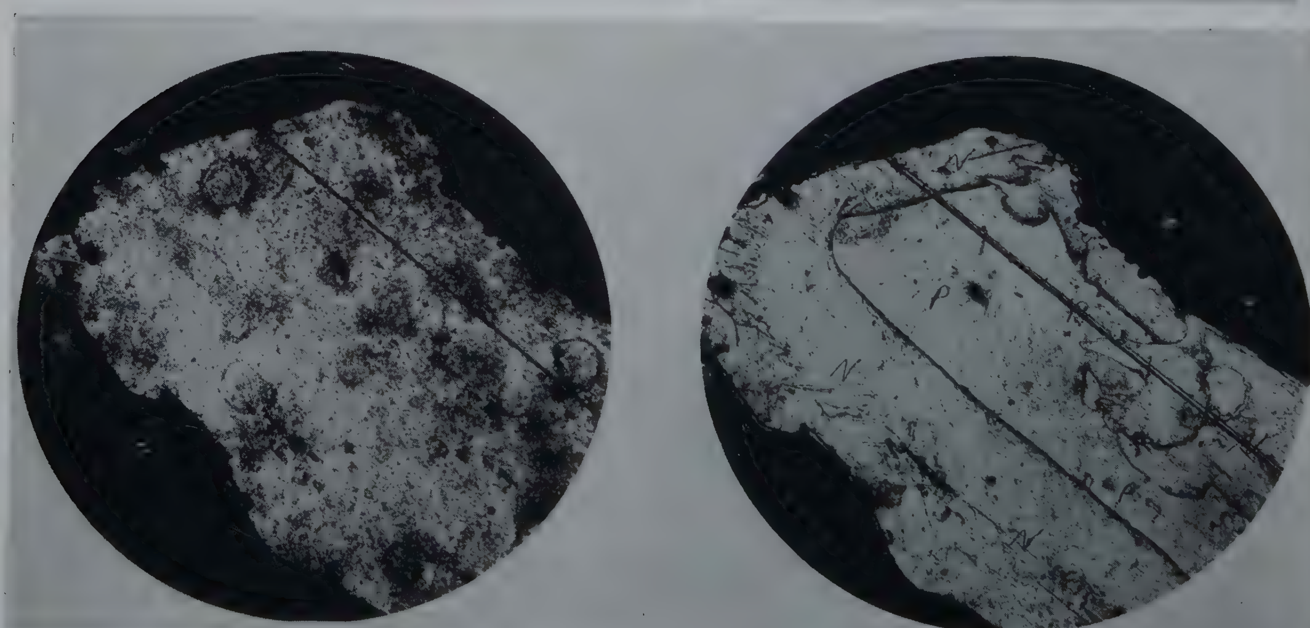



**FIG 10—(*a*) Grain in rapidly-cooled ingot of lot 1. Etched in warm 5 pct KOH. (*b*) Same grain, after etching in acid mixture followed by re-etching in KOH. P-N barrier is now visible. × 50.**
Reduced approximately one-third in reproduction.

# Book Reviews

## The Measurement of Stress and Strain in Solids

*Institute of Physics, 47 Belgrave Square, London, S.W.1, England, 1948. 114 pp., illus., diagrs., charts, tables, 9½ x 6 in., linen, 17s.6d. plus 10d postage; U.S.A. $4.00.*

REVIEWED BY C. ZENER

This book consists of a collection of papers presented to a conference upon the measurement of stress and strain, held at Manchester during the summer of 1946. Many methods of measurement are discussed, the most important employing resistance strain gauges, X-rays, photo-elasticity or acoustical strain gauges. By far the greatest emphasis is given to resistance strain gauges.

The paper reviewing the physical characteristics of wire-resistance strain gauges should be of value to anyone using such gauges. Particular attention is given to such practical details as the relative merits of different types of wires, the various types of cement, proper drying procedures, and creep characteristics. One type of cupronickel wire consistently extended to 4 to 5 per cent before fracture.

An original paper upon high frequency strain gauges is of interest both to those interested in the use of strain gauges and to those interested in the physics of metals. It is found that the sensitivity of strain gauges of ferromagnetic wires is increased by a factor as large as 20 when high frequencies are used. The author anticipates that a search for special ferromagnetic wires will raise the high frequency sensitivity still further.

## Principles of Metallography

*R. S. Williams and V. O. Homerberg. 5th ed. McGraw-Hill Book Co., 1948. 319 p., illus., diagrs., charts, tables, cloth, $4.00.*

This standard text for students of general science and engineering puts greater emphasis on the applications of metallography than on the physiochemical principles involved. In the new edition the major changes have been in revisions and additions to the sections on copper, magnesium, and aluminum alloys, on the hardening and tempering of steel, and on the general question of "hardenability."

## Theoretical Structural Metallurgy

*By A. H. Cottrell. Longmans, Green & Co., New York; Edward Arnold & Co., London, 1948. 256 p., diagrs., charts, tables, 8¾ x 5½ in., cloth, $5.25; 21s.*

Written for metallurgical students, this book presents the ways in which ideas of atomic mechanics can be applied to problems of metals and alloys. Based on a theoretical outlook, there is no discussion of experimental methods. The treatment is mainly descriptive, and mathematics is confined to an elementary level. A certain amount of introductory material is included, and the selection of topics is centered around the electron theory of metals and the statistical thermodynamics of metals and alloys.

## Treatise on Powder Metallurgy

*Volume I, Technology of Metal Powders & Their Products, by Claus G. Goetzel, Ph. D., Vice-President and Director of Research, Sintercast Corp. of America, N. Y. Published by Interscience Publishers, Inc., New York, N. Y. Cloth, 806 pages, 300 illustrations, 82 tables, $15.*

This encyclopedic treatment of powder metallurgy presents to the novice, the expert, the development engineer, and the inventor, twenty chapters of principles, history, theory, experiment, technology, properties, production, and application. Coverage is so complete that the volume is equally useful as an introductory text, a reference book, a source for new applications, and a stimulus to new developments and new processes.

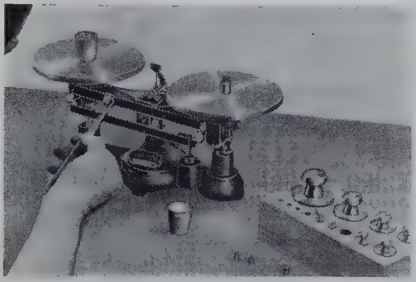
The fundamentals covered by this volume equip the reader to understand the most recent evolution of the art, such as structural iron and steel components, "infiltrated" powder metal products, superalloys, new magnetic materials, and combination materials (metal-metalloid and metal-ceramic).

The book is particularly effective as a text because it starts at the beginning, defines words, and explains the terminology of the powder metallurgist. Chapters on basic principles and history help to orient the student in the overall field of metal processing. Following the orientation, there are chapters which describe methods of powder production, characteristics, properties and standards of available powders, methods of testing powders, powder conditioning, and the function of addition agents.

## *AMONG THE MANUFACTURERS:*

### Stainless Steel Balance

A new Harvard trip balance features stainless steel weighing platforms and beams and is available through scientific supply dealers. Made by Ohaus Scale Corp., 10-14 Hobson St., Newark 8, N. J., it is designed for use in many fields, including industrial laboratories. The stainless steel weighing platforms are said to be proof against heat, corrosion, chemicals or accidental impact. The stainless relief etched beams give clear readings. Polished agate bearings work against precision hollow ground tool steel knife edges. The balance in the photo has a beam capacity of 210 grams.

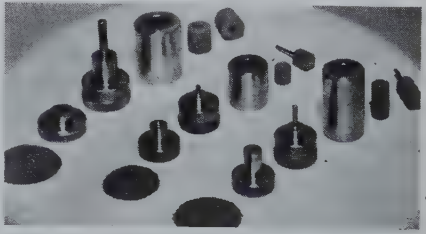


### Aluminum Cold Solder

A body solder made from aluminum powder that requires no heat, hence does not damage adjacent painted surfaces, is announced by Reynolds Metals Co., 2500 S. Third St., Louisville, Ky. It replaces the older type solders which had to be melted and flowed in to dents and other damaged areas of automobile bodies. Several successive applications can be employed to build up thicknesses as much as one inch. These cold solders are doughlike, about the consistency of plastic wood. When applied by spatula or wiper, the solvent evaporates and the metal mass soon hardens sufficiently to be filed or sanded. It adheres strongly to a properly cleaned surface. When sanded smooth, it provides an excellent base for paint, enamel or lacquer coatings. The accompanying photograph shows a dent with a hole in it; then a similar dent and hole that have been filled with the cold solder; then the repaired spot has been smoothed off to show how the material blends.

### Cemented Carbide in Molds

Lining of the mold barrels for forming abrasive wheels with Carboloy cemented carbides has greatly reduced wear, multiplied mold life five to ten times, promoting better finish and less breakage, according to Carboloy Co., Inc., Detroit 32, Mich. The molded wheels are also more easily removed



from lined steel molds. No alteration in mold design to switch over to carbide-lined molds was necessary. Some of these lined molds have produced over 10,000 units each.

### Manufacturers' Publications

Baker & Co., Inc., Newark 5, N. J., has just published a 248-page Bibliography of the Platinum Metals, 1931-1940, with about 7000 references. It is strongly bound in buckram with a palladium leaf title on the front cover and backbone.

The Allis-Chalmers Mfg. Co., Milwaukee 1, Wis., has just published a highly-illustrated annual review of engineering developments for 1948. One section is devoted to metals, one of the interesting references being devoted to increasing the supply of either high or low purity oxygen by applying Allis-Chalmers turbo-blower units.

"Nickel Topics" for March contain the usual interesting variety of topics on subjects pertaining to nickel. Published by the International Nickel Co., Inc., a leading article is on new ductile cast iron. A bit hair-raising are an article and photos on stainless steel alloy skull templates for skull surgery. Thus there are eight standard designs fabricated by Uza Nudell, New York, specialist on this bizarre fabrication. Slots radiating toward the center from the periphery allow the plate to be bent at the time of the operation to make it fit more exactly the contour of the individual skull. Perforations near the center allow the escape of fluids and permit skin tissues to grow through them.

"Corrosion Control for Underground Pipe" is a well-published 26-page booklet issued by the Owens-Corning Fiberglas Corp., Toledo 1, Ohio. It portrays in text and telling photos the role of Fiberglas pipe wrap in corrosion control. Test data on the properties and performance of the wrap are included.

### Men of Industry

F. L. LaQue, International Nickel Co., Inc., has been named recipient of the Frank Newman Speller Award in Corrosion Engineering of the National Assn. of Corrosion Engineers. During the past year he has served as this association's president.

Roy Perkins has been appointed manager of the blast furnace department of F. H. McGraw & Co., having had about 20 years of blast furnace construction experience.

Charles A. Freeman has resigned from the A. P. Green Fire Brick Co. to form his own company at Canyon City, Colo. He was instrumental in developing the use of Missouri fire clays for blast furnace service. He belongs to several technical societies.

Ronald E. Griffiths, for three years supervisor of the American Steel & Wire Co.'s research laboratory in Cleveland, has been made assistant director of research for the company. He started with that company as a metallurgical observer at the Cuyahoga works.

Melvin C. Harris has resigned as vice president in charge of production of the Allegheny Ludlum Steel Corp., having been with the company since 1915, in later years serving as plant manager and manager of production.

## Open Hearth Optical Pyrometer

An optical pyrometer especially designed for taking temperature readings of the limited range required for molten

ferrous metals has been developed by the Pyrometer Instrument Co., Inc.. Bergenfield, N. J. The reading scale has been lengthened over 40 per cent and covers only the critical portion of the temperature range required. The standard temperature scale for black body conditions permit coverage from 2200 to 3000 F and an additional scale in red, corrected for the emissivity of molten iron, steel, Monel, etc., reads from 2400 to 3300 F. Both scales are sub-divided into wide 10 deg. divisions so that readings can be made to within a very few degrees. The black body scale is good for measuring temperatures of furnaces, ovens, linings, fire boxes, etc., whereas the red scale gives quick readings of spout, pouring and ladle temperatures of molten iron, steel, Monel and other ferrous alloys.

## Faster Machining Steel

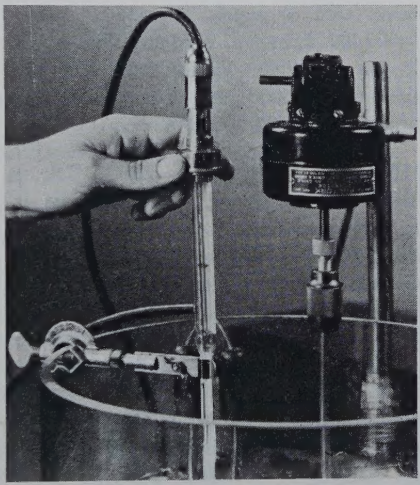
A new steel that can be machined 10 to 25 per cent faster than the fastest standard free-machining Bessemer screw stock in commercial use is announced by the Jones & Laughlin Steel Corp. This new "E" steel can now be furnished in cold-finished bars. Compared with B-1113, the former "king" of the Bessemer screw steels, with a machinability index of 135, this "E" steel has an index of 170, or nearly 25 per cent higher. It has a smoother finish after machining, better cold working and cold forming properties and gives longer tool life on screw machines than its predecessor, according to its sponsor. Comments by users of this new steel were that the finish was excellent, tool life was doubled, with production increased 10 or 15 per cent.

## New Resistance Alloy

Unusual high electrical resistivity and ability to retain stable resistance values over wide ranges of temperature are characteristic of "Karma," a new alloy developed by Driver-Harris Co., Harrison, N. J. It is especially suitable for high accuracy wire-wound resistors. In comparison with copper-base alloys now used for such resistors the specific resistance of Karma is exceptional. At 20 C it is 800 ohms per circular mil foot (133 microhms/$cm^3$)—more than 2.7 times that of either Manganin or Advance, state the sponsors. This makes for small resistors, with savings of space and weight and more ohms per production dollar. The new alloy also has higher tensile strength which permits faster winding speeds.

## Micro-set Thermoregulator

A new immersion-type micro-set thermoregulator for laboratory use in controlling liquid temperatures in water and oil baths, or air temperatures in



ovens, etc., is announced by Fisher Scientific Co., 717 Forbes St., Pittsburgh 19. It has a sensitivity of plus or minus 0.02 F over a range of 50 to 220 F. Only 15 in long, its patented design eliminates an outer shell so that there is a minimum of lag in response to slight temperature changes. It has a quick adjustment sleeve that magnetically moves one of two electrodes so that the regulator will turn heating devices on and off to maintain any temperature within its range. The device has two capillaries, one with mercury enclosing a tungsten electrode and the other containing mercury that rises and falls with temperature to make or break contact with the upper metallic electrode. Contact points are sealed in hydrogen under pressure, eliminating corrosion.

**Advertisers' Index**



## PROFESSIONAL SERVICES

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*A weekly bulletin of engineering positions open is available to members of the cooperating societies at a subscription of $3.50 per quarter or $12 per annum, payable in advance.*

## POSITIONS OPEN

**PROCESS METALLURGIST** for process development and semi-works production of metals by chemical or electro-furnace reduction. Write stating qualifications, experience and salary expected. Location, New Jersey. Y1646.

**RESEARCH METALLURGIST,** 30-40 graduate, with non-ferrous smelting and refining experience, to supervise development of hydro-metallurgical pyro-metallurgical and electrolytic refining methods. Salary, $4200-$4800 a year. Location, northern New Jersey. Y1926.

**MINE AND SMELTER DRAFTSMAN** with considerable experience on the processing end of mining and smelting equipment. Salary open. Location, New York, N. Y. Y2340.

**FOUNDRY SALES MANAGER,** not over 45, with gray, malleable and steel foundry experience, and background in metallurgical or mechanical engineering for Midwestern production foundry. Salary, $12,000-$16,000 a year. Y2342.

**CHEMIST-ASSAYER,** graduate, experienced in fire assaying and wet determinations of lead, zinc, copper, gold, silver, tin, tungsten, bismuth, antimony ores and concentrates, to take charge of laboratory employing twenty workmen and handling about 9000 assays monthly. Standard three-year contract. Working knowledge of Spanish essential. Salary, $4200 a year, plus one month's bonus; single status preferred; if married single status for six months, free transportation to Bolivia by air for employee and wife, free living quarters, four weeks' vacation yearly. Y2344.

**PRODUCTION MANAGER,** 35-45, mining graduate, with supervisory mine, mill, smelter and non-ferrous metal products fabrication experience, to take general charge of production. Knowledge of Spanish desirable. Salary open. Location, Argentina. Y2396CDS.

**METALLURGIST,** graduate, 25-35; fair amount of metallurgical experience, with high melting refractory metals and alloys for employment in research and development with a metals company. Salary, $300-$400. Location, northern Illinois (a). Recent Graduate Engineer or one with limited experience for above. Salary approximately $250(b). R5629.

**METALLURGISTS,** 2, 23-35, B.S. in Metallurgy or Mining; some practical experience necessary for one of them. In lieu of experience, a graduate who specialized in ore-dressing problems would be acceptable for one of the jobs. Duties will be to conduct ore-dressing investigations (mainly flotation tests and microscopic examinations) in the research laboratories and supervising special tests in the concentrators. Must be single, or single status till housing is available. Salaries, $2700-$3900 a year. Location, South America. Y-798.

**METALLURGISTS.** (a) Metallurgist-Mill Foremen, experienced college graduates. Knowledge Spanish. Three year contract. Starting salary, $5000 a year plus bonus and living quarters. Single preferred; if married, single status for 6 months. Transportation paid. (b) Junior Metallurgist, graduate, with some experience in ore dressing and laboratory test work; single status. Standard 3 year contract; base starting salary $3000 a year plus bonus; knowledge Spanish desirable. Transportation furnished to Bolivia by air. Four weeks' vacation plus free living quarters. Y-988.

**PROCESS METALLURGIST** for process development and semi-works production of metals by chemical or electro-furnace reduction. Write stating qualifications, experience and salary expected. Location, New Jersey. Y-1646.

**RESEARCH METALLURGIST,** 30-40, graduate, with non-ferrous smelting and refining experience, to supervise development of hydro-metallurgical pyrometallurgical and electrolytic refining methods. Salary, $4200-$4800 a year. Location, northern New Jersey. Y-1926.

**METALLURGIST OR METALLURGICAL ENGINEER,** young, B.S. degree, to study metals and processes used in electron tube development and manufacture. Tungsten, molybdenum, nickel, nickel alloys, copper and stainless steel alloys are the principal metals involved. Principal processes are work with the joining of metals by brazing and welding techniques. Location, southern New Jersey. Y-2144(a).

**TEACHING PERSONNEL** in the field of metallurgy and metal processing. (a) Instructors, Doctor's degree or New York State Professional Engineer's license with experience in teaching and industry. Salary, $3000-$5400 a year. (b) Assistant Professor with Doctor's degree or New York State Professional Engineer's license and experience in teaching and industry. Salary, $3900-$6767 a year. (c) Lecturer, qualified to obtain Doctor's degree or holding a P.E. license in other states entitling him to take examination in New York. Salary open. Location, New York, N. Y. Y-2215.

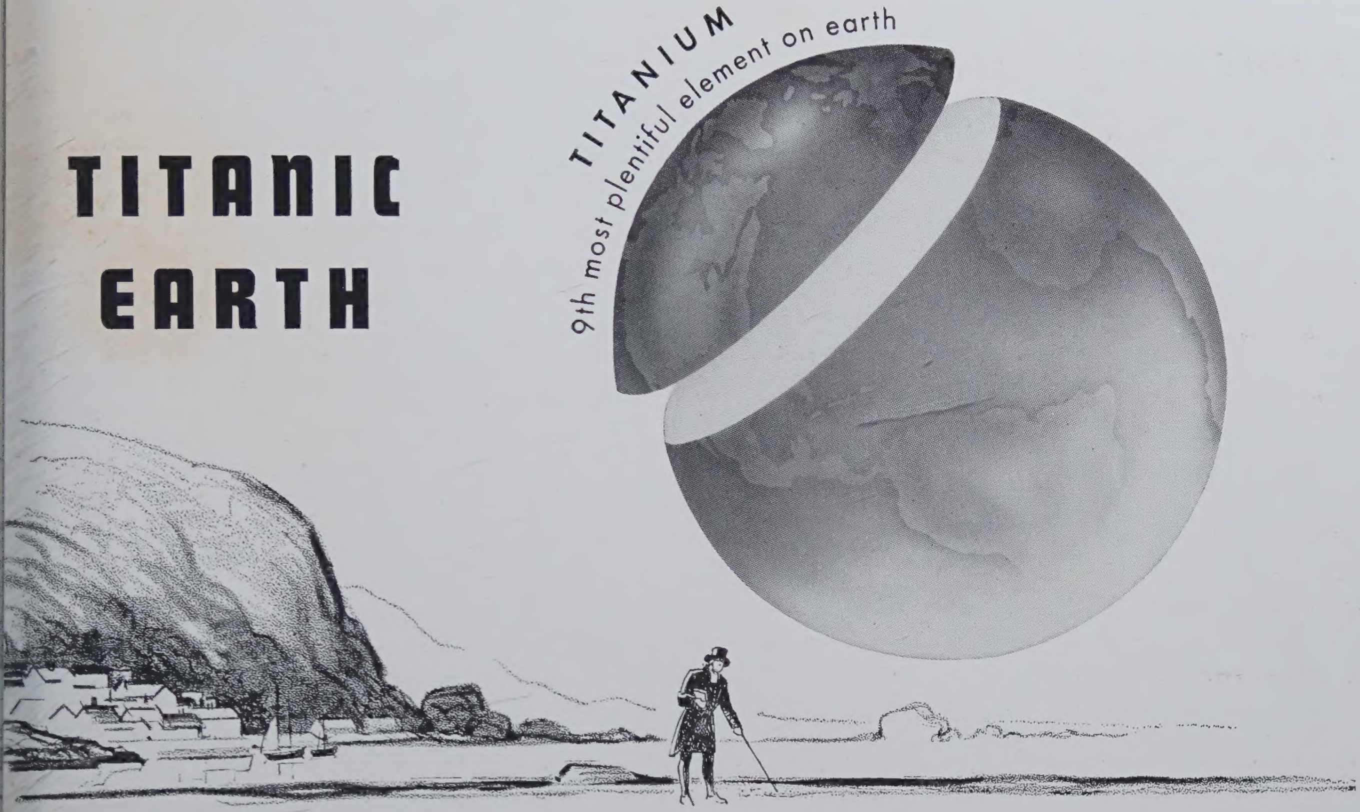
## MEN AVAILABLE

**METALLURGICAL ENGINEER,** B.S. in Metallurgical Engineering, 26, married. Six years' experience including two and one-half years' ferrous welding research, one year magnesium and aluminum production and sales, two and one-half years' college teaching in engineering. Desires research or teaching position in East. Available June. M-420.

**ENGINEER AND EDUCATOR,** young, married, several years' experience in the mineral industries, research, and teaching. Doctorate and graduate of several well known universities. Desires position in the academic field. Deanship or chairmanship of a department of metallurgy is preferred. Some teaching duties along with the administrative functions is desired. M-431.

**METALLURGIST - MECHANICAL ENGINEER,** 25, married. Mechanical Engineering degree, some graduate work in Metallurgy; 3½ years' diversified metallurgical quality control experience in integrated steel tube plant. Seeks responsible metallurgical or mechanical engineering position. Colorado to West Coast preferred. M-433.

# TITANIC EARTH




## TITANIUM DISCOVERED

Back in 1791 an English clergyman, William Gregor, who liked to stroll and think on the beaches of Cornwall, became curious about the black sand he saw there. This gentleman of the cloth was also an amateur chemist and in this sand he discovered a new element. Almost coincidentally an Austrian named Heinrich Klaproth (also discoverer of uranium and zirconium) extracted the same thing from rutile and named it "Titanic Earth" for the mythical Titans. Hence our name Titanium.

Thereafter titanium was found in various places including the Ilmen Mountains of Russia (ilmenite) but although it is the ninth element in order of earthly abundance, it remained a mere laboratory curiosity until 1908.

## TITANIUM OXIDE

At that time Dr. A. J. Rossi, expert in the reduction of metals, mixed titanium oxide with salad oil to make a white paint. In another 10 years a pure oxide was being produced which quickly won success as a pigment. Paint, false teeth, face powder, tires, shoes, glassware, textiles, inks, plastics, paper consumed an increasing tonnage of titanium oxide but still the pure metal was beyond industry's reach.

## TITANIUM METAL & NATIONAL RESEARCH

Titanium is an affectionate metal, over fond of oxygen and nitrogen when at high temperatures. Even a fraction of a per cent of either makes titanium of little value as a structural material. Until recently there was no means of preparing titanium metal in a form sufficiently free of these elements to indicate any potential commercial value. Dr. W. J. Kroll of the Bureau of Mines has initiated many of the recent developments in titanium metallurgy by finding a means of preparing powdered titanium metal.

Only by exclusion of these gases can it be kept from embrittling combinations and when Remington Arms Company, a Du Pont subsidiary, laid its plans to produce metallic titanium in cast and rolled shapes, they knew that at National Research Corporation they could find the knowledge of vacuum technique that they needed.

The melting and casting of titanium was a natural for National Research. We planned the process, designed the equipment and installed it. Today this National Research Corporation pilot equipment is handling the highest quality of commercial metal — not much compared with aluminum — nothing at all compared with steel — but so promising that millions will be spent by the industry within a few years to increase the quantity and lower the price.

## USES OF TITANIUM METAL

Titanium stands fourth in abundance among the structural metals and there is plenty in the U. S. A. Tremendous strength, light weight, and remarkable corrosion resistance (comparable only to that of the noble metals) is a unique combination. Coming at a time when long-sighted people are viewing our metallic resources with alarm, it has an assured future. With the price pulled down to a few dollars a pound or less, titanium will be of primary importance to manufacturers of aircraft, automobiles, electric devices, gas turbines, superchargers, marine hardware, rockets, optics, jewelry.

## WHAT NEXT?

So, with the help of National Research's high vacuum know-how, another material has been taken from the test tube to the factory. Where else can good men and ideas help — where can they help you? At National Research the best in brains, organization, equipment, and an unequalled accumulation of unique experience are available.

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